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Montana Greenhouse Gas Emissions Inventory

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Estimate for 1990

Phase I Report

Prepared by

Montana Department of Environmental Quality

January 1997

Supported by a grant from the

U.S. Environmental Protection Agency

to the

Montana Department of Environmental Quality

Grant Number: 824211010

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Executive Summary

The purpose of this report is to provide a comprehensive and detailed baseline inventory of Montana 1990 greenhouse gas emissions. The year 1990 was chosen as the baseline because the United States has signed the Framework Convention on Climate Change with a goal of attempting to reduce emissions to 1990 levels by the year 2000. This inventory covers the four primary greenhouse gases emitted as a result of human activity. These are carbon dioxide, methane, nitrous oxide, and halogenated fluorocarbons. Emissions were estimated for the five major source categories including energy, production processes, agriculture, waste management, and land use. Emissions were estimated primarily by using the methodologies given in the State Workbook - Methodologies for Estimating Greenhouse Gas Emissions (EPA, 1995).

The Montana inventory was funded by a grant from the U.S. Environmental Protection Agency Climate Change Division, State and Local Outreach Program. This greenhouse gas emission inventory is the first phase of a larger study. The Montana Department of Environmental Quality was awarded an EPA grant in September 1996 to develop a greenhouse gas action plan to manage and reduce greenhouse gas emissions in Montana to 1990 levels. This plan will be developed through collaboration among state and local government, industry and nonprofit organizations. The results of the inventory will be used as a basis for the action plan.

Comprehensive results of this inventory are given in Chapter 7. Specific results from the energy, production processes, agriculture, waste management and land use categories are provided in the emission results section of each chapter. Land use related greenhouse gas calculations are complex. Land management activities serve as both a source of carbon emissions (mainly through timber harvest) and as carbon storage or sequestration (mainly through fire suppression). Net carbon dioxide emission from timber harvest minus carbon stored in wood products was equivalent to about 10 million tons in Montana in 1990. Carbon sequestration mainly in the form of forest fire suppression was equivalent to about 14.6 million tons of carbon dioxide in 1990. However, sequestration from fire suppression is temporary. At some time the stored carbon will burn and result in carbon emissions. For this reason, carbon dioxide emissions and sequestrations from land management activities are reported separately in this inventory.

Carbon dioxide is the major greenhouse gas emitted in Montana, accounting for 74 percent of 1990 emissions. Methane accounted for about 14 percent of 1990 greenhouse gas emissions. Halocarbons are responsible for 9.5 percent of emissions, and nitrous oxide 2.5 percent. The reactant level of greenhouse gases is quantified in term of carbon dioxide equivalent. A total of about 40 million tons of carbon dioxide equivalent greenhouse gases were emitted as a result of human activity in Montana in 1990. Energy related emissions account for 72 percent, production processes and agriculture each about 12.5 percent and waste related 3 percent. In 1990 Montana imported energy with emissions totaling about 23 millions tons of carbon dioxide equivalent, and exported about 72 million tons of carbon dioxide equivalent emissions.

The consumption of fossil fuels is the major source of greenhouse gas in Montana, accounting for 71 percent of emissions. The use of petroleum accounts for 53 percent, coal 35 percent, and natural gas 12 percent of fossil fuel-based greenhouse gas emissions in Montana in 1990. The next largest source of greenhouse gas emissions in Montana is halogenated fluorocarbons from aluminum production, accounting for 11 percent of emissions. Methane emissions from domesticated animals are the next largest source of greenhouse gas emissions in Montana in 1990 at 10 percent. All other sources combined total about 8 percent of greenhouse gas emissions.

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Chapter 1. Introduction

I. Study Objectives

The primary objective of the Montana Greenhouse Gas Emissions Inventory - Base Year 1990 - is to develop a comprehensive report identifying the sources, types, and quantity of greenhouse gas emissions and sinks in Montana during 1990.

The year 1990 was chosen as the baseline because the United States has signed the Framework Convention on Climate Change with a goal of attempting to reduce emissions to 1990 levels by the year 2000. This information is important because climate change has serious global consequences and could affect Montana. Compiling an emissions inventory is a critical first step toward developing policies and strategies to mitigate greenhouse gas emissions and to assess the various options available for responding to the effects of climate change.

A second objective of the inventory is to develop appropriate methods to calculate greenhouse gas emissions for Montana. This will allow comparison with future statewide inventories and an ability to evaluate emission reduction strategies.

Greenhouse gas emissions are rarely measured directly or reported to statistical agencies. Instead, they are inferred from information collected for other purposes. The EPA State Workbook (1995) presented methods to assist states in identifying and estimating their emissions of greenhouse gases. These methods were adapted from Volumes 1-3 of the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC, 1994) and the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993 (EPA, 1994). The Montana Greenhouse Gas Emissions Inventory was based on the methods described in the State Workbook, except in cases where data were insufficient or where state-specific data allowed a more refined emissions estimate. Departures from the EPA State Workbook methodology have been detailed in this inventory.

I I. Study Organization

The greenhouse gases estimated in Montana include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halogenated fluorocarbons (carbon tetrafluoride, CF_4 and carbon hexafluoride, C_2F_6). Table 1.1 identifies the major human-caused greenhouse gas emissions and associated activities in Montana. Emissions from each type of greenhouse gas are identified and computed and reported in the results section of each chapter.

The EPA State Workbook (1995) divided emissions into twelve sections, including three which either are not applicable or insignificant in Montana. Emissions from flooded rice fields, manure management and burning of agriculture crop waste are not calculated for Montana and are explained in the agriculture

chapter. The other nine sections were lumped into five chapters for the Montana Inventory. Energy related emissions (Chapter 2) include carbon dioxide emissions from the combustion of fossil and biomass fuels and methane emissions from natural gas and oil systems and coal mining. Sources of greenhouse gases from production processes (Chapter 3) include aluminum production and lime processing. Agriculture related emissions (Chapter 4) include methane emissions from domesticated animals and nitrous oxide emissions from fertilizer application. Waste related emissions (Chapter 5) include methane emissions from municipal wastewater and landfills. Land use activities (Chapter 6) cover both carbon dioxide emissions and uptakes or sinks from forestry and other land uses. The report concludes (Chapter 7) with a summary of results for all greenhouse gas emissions from Montana and recommendations for next steps.

At a national level, the energy sector contributes to almost 80 percent of the total greenhouse gas emissions. In addition, detailed data are collected for energy use. Therefore, the energy sector is broken down into residential, commercial, industrial, transportation and electric utility sectors. Montana is a net exporter of both energy and greenhouse gases. Greenhouse gas emissions produced in the process of meeting Montana's energy needs are computed and reported separately from those generated in producing energy that is exported of out state. This information is reported in the interstate transfers section of Chapter 2.

Table 1.1. Major Human Caused Greenhouse Gas Emissions and Associated Activities in Montana.

SOURCE	Carbon Dioxide CO_2	Methane CH_4	Nitrous Oxide N_2O	Halogenated Fluorocarbons HFC
Energy Related				
Fossil Fuel Combustion	X			
Biomass Fuel Combustion	X			
Natural Gas and Oil Systems		X		
Coal Mining		X		
Production Processing				
Lime Processing	X			
Aluminum Manufacturing	X			CF_4 & C_2F_6
Agriculture Related				
Domestic Animals		X		
Fertilizer Applications			X	
Waste Related				
Municipal Wastewater		X		
Landfills		X		
Land Use Related	X			

III. Global Climate Change and The Greenhouse Effect

The retention of heat by the Earth's atmosphere is a natural phenomenon crucial to life on Earth. The underlying scientific principles are well known. Incoming visible light from the sun is absorbed by the atmosphere and the surface of the earth. Some of the energy is radiated back toward space as infrared light. Much of the radiated heat is trapped by water vapor and other trace gases in the atmosphere. This natural phenomenon keeps the earth's surface about 55 degrees Fahrenheit warmer than if the sun's heat were not trapped by these gases (EPA, 1995). The effect is similar to a horticultural greenhouse (hence the term greenhouse effect), which uses glass to trap the sun's energy as heat. Without this natural greenhouse effect, life on earth as we know it would not be possible.

Human actions have increased the level of trace gases in the atmosphere causing concern for potential climatic changes (IPCC, 1992). These trace gases termed greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HFC's), and perfluorinated carbons (PFC's). About one percent of the atmosphere is water vapor. Water vapor is not included in this inventory because human activity has an insignificant impact on natural sources and sinks of water vapor including evaporation from the oceans, precipitation, absorption and transpiration by plants and glacial ice (DOE/EIA, 1995).

Extensive study shows that not all greenhouse gases contribute equally to trapping the Earth's heat. Scientists have created an index to compare climatic heating effects of different gases over various time scales. They term this the global warming potential (GWP). Each greenhouse gas has been assigned a numerical rating to indicate its GWP in relation to the GWP of an equal amount of carbon dioxide. This inventory uses global warming potential values recently released by the Intergovernmental Panel on Climate Change (DOE/EIA, 1995). Carbon dioxide has a GWP of one, for comparison purposes. Methane, by contrast, has a GWP of 24.5, meaning that a volume of methane has 24.5 times the effect on climate of an equal volume of carbon dioxide. Nitrous oxide has a GWP of 320. HFC's and PFC's have GWP ranging from 150 to 10,000 (EPA, 1994). The only halogenated fluorocarbons generated in Montana are carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6) which have atmospheric residence times in excess of 10,000 years and have an estimated GWP of 8,400 (Abrahamson, 1992). Emission estimates are often reported in carbon dioxide equivalent emissions to incorporate the GWP of different gases and offer comparative estimates between different gases. For example, landfill emissions in Montana in 1990 totaled about 38,663 tons of methane, about 947,244 tons of carbon dioxide equivalent.

IV. Response To Climate Change

In response to early findings about climatic change, the Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the United Nations Environment Program and the World Meteorological Organization. The IPCC is a group of 2,500 scientists charged with assessing the science of climate change under the Framework Convention on Climate Change. In 1996, the IPCC issued its most recent findings on climate change, stating, "For the first time the balance of evidence suggests there is a discernible human influence on the earth's climate, or to put it another way, the changing climate over the last 100 years cannot be explained by natural variability alone." Timothy Wirth, Under Secretary for Global

Affairs, responded to this finding at the Second Conference of the Parties Framework Convention on Climate Change: "This seemingly innocuous comment is in fact a remarkable statement: for the first time ever, the world's scientists have reached the conclusion that the world's changing climatic conditions are more than the natural variability of weather. Human beings are altering the Earth's natural climate system" (1996).

IPCC findings (1995) showed that since 1850 atmospheric concentrations of carbon dioxide have increased 30 percent, methane has increased by 145 percent, and nitrous oxide concentrations have risen by 15 percent. IPCC concludes that a doubling of 1850 atmospheric concentrations of carbon dioxide equivalent (predicted to occur by 2050 at current rates) could result in an average global temperature increase of 1.5 to 4.5 degrees Celsius (3 to 8 degrees Fahrenheit). Despite these increases, it is impossible at this juncture to predict with certainty the timing, magnitude, or regional distribution of any climate change.

Although there is scientific consensus on many issues surrounding the global warming debate, confusion still exists about the facts. The following is a summary of scientific consensus concerning the different aspects and "levels of uncertainty" associated with the global warming issue.

"Virtual certainty" represents nearly unanimous agreement among scientists, with no credible alternative view existing. "Very probable" represents roughly a 90 percent probability, and "probable" represents roughly a 67 percent chance. These levels of certainty were drawn from a presentation by Dr. Jerry Mahlman of the National Oceanic and Atmospheric Administration at the International Conference on Climate Change, July, 1994 and from the IPCC Special Report, 1994, and reported in the Minnesota Greenhouse Gas Inventory (Center for Energy and Environment, 1995).

There is virtual certainty that:

- There is a natural greenhouse effect that keeps earth warmer than it would otherwise be.
- Greenhouse gas concentrations in the atmosphere are increasing due to human activities.
- Added greenhouse gases cause added heating.
- Significant reduction in uncertainty will require a decade or more, but climate recovery will require many centuries.

It is very probable that :

- There will be an increase in average global temperatures, a reduction of northern sea ice and a rise in the global sea level.

It is probable that:

- There will be increased summer dryness at mid latitudes.

Uncertainty among the scientific community remains about:

- Regional details of climate change, tropical storm increases, and the probable change in climate in the next 25 years.

Despite the uncertainties associated with climate change, some organizations already are taking action. The insurance, banking, and electric industries are realizing that global warming is a risk (Rocky Mountain Institute, 1996). Industry examples include 40 insurance companies (none American) which signed a declaration in November 1995 committing themselves to help reduce the threat of climate change. Eight Canadian electric utilities, serving more than half of the customers in Canada, recently formed the Greenhouse Emissions Management Consortium. Their goal is to demonstrate industry leadership in support of voluntary and market based approaches to management of greenhouse gas emissions (Donnelly, 1996). Some governments are taking actions. The Association of Small Island States has proposed aggressive policies to reduce global greenhouse gas emissions. They fear their island populations would be severely affected by rising sea level.

At the Earth Summit in Rio de Janeiro in 1992, the U.S. signed The Framework Convention on Climate Change. A total of 167 countries have now signed the Convention which outlines measures for dealing with the threat of climate change and has the following objective:

> ...achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

As a start, the U.S. and other industrialized countries have committed to aim to reduce greenhouse gas emissions to 1990 levels by the year 2000 in accord with the Framework Convention on Climate Change (Clinton, 1993). Secretary of State Warren Christopher (1996) said that the U.S. supports emission reductions: "We will seek agreement on further cuts in greenhouse gases to minimize the effects of climate change." The U.S. has concluded that the next step is the adoption of a realistic but binding target for greenhouse gas emission reductions (Wirth, 1996). The meeting to negotiate that treaty will take place in the fall of 1997. The U.S. has approximately 5 percent of the world's population, but generates about 22 percent of all greenhouse gases. About 50,000 pounds of greenhouse gases were emitted for each U.S. citizen in 1990 (DOE/EIA, 1995).

In addition to national and international actions, a number of states are also creating inventories and developing strategies to reduce greenhouse gas emissions. The Montana Greenhouse Gas Inventory is part of Montana's effort to join the nation in meeting the global warming challenge. The Montana Inventory was funded by a grant from the U.S. Environmental Protection Agency Climate Change Division, State and Local Outreach Program. Twenty-nine states and Puerto Rico are working in partnership with EPA to complete statewide inventories and action plans.

Montana would not be alone in addressing climate change. Examples of recent actions in other states include the following. New York and Vermont have pledged to cut carbon dioxide emissions by at least 15 percent over the next 15 years. Oregon enacted a law in July 1989 requiring a 20 percent reduction

in greenhouse gas emissions by 2005. A California law calls for the California Energy Commission to study the potential impact of climate change on the state's energy supply and demand, economy, environment, agricultural and water resources. The Connecticut legislature directed in 1992 that a carbon dioxide emissions reduction goal be included in the state energy plan. A recent Connecticut decision requires new facilities which generate large increases in transportation to mitigate for the increased vehicle miles traveled (Belanger, 1996). Wisconsin has developed and is implementing a strategy for cleaning the air, protecting the climate, and sustaining the economy (Hargrave, 1995). The Minnesota Department of Public Service adopted higher levels of energy efficiency standards and the initiation of an energy efficiency program focused on the reduction of carbon dioxide emissions. And the Minneapolis and Saint Paul city councils adopted a carbon dioxide reduction plan in December, 1993.

V. Potential Affects

Human health, terrestrial and aquatic ecological systems, and socioeconomic systems such as agriculture are all vulnerable to climate change and depend not only on a system's sensitivity but also on its ability to adapt to new climatic conditions. Both the magnitude and the rate of climate change are important in determining the sensitivity (how a system responds to given changes in climate), adaptability (to what degree are adjustments possible in response to changes in climate), and vulnerability (how susceptible to damage or harm from changes in climate) of a system. Most impact studies have assessed how systems would respond to climate change resulting from a doubling of equivalent carbon dioxide concentrations. The potential affects discussed below are based on results from computer modeling scenarios using carbon dioxide equivalent concentrations equal to twice pre-industrial concentrations.

Climate change is likely to have wide-ranging and mostly adverse impacts on human health, with the possibility of significant loss of life from both direct and indirect pathways (IPCC, 1995). Direct health effects include increased death and illness due to an anticipated increase in the intensity and duration of heat waves. Temperature increases in colder regions could result in fewer cold-related deaths. An increase in frequency and intensity of extreme weather (storms, floods, etc.) would cause a higher incidence of death, injury, and exposure to contaminated water supplies. Indirect effects are expected to predominate in the long term and include increases in the potential transmission of insect-borne infectious diseases such as malaria resulting from extensions of the geographical ranges and longer survival season for disease organisms.

Computer simulations of potential impacts to terrestrial and hydrologic ecosystems (IPCC, 1995) suggest that a one degree Celsius increase in global mean temperature is sufficient to cause changes in regional climates that will affect the growth and regeneration capacity of forests in many regions. Under doubled equivalent carbon dioxide equilibrium conditions, a global average of one-third (estimates vary from one-seventh to two thirds) of the existing world's forested areas will undergo major changes in broad vegetation types. Deserts are likely to become more widespread and desertification is more likely to become irreversible. Computer models project that between one-third and one-half of the existing mountain glacier mass could disappear over the next 100 years. Inland aquatic ecosystems will be influenced by climate change through altered water temperatures, flow regimes and water levels.

Potential impacts from climate change would affect socioeconomic systems such as agriculture (IPCC, 1995). Models indicate that total global agriculture production may not change, but that crop yields and

changes in productivity due to climate change may shift from formerly productive regions. This conclusion takes into account the beneficial effect of carbon dioxide as a fertilizer for some crops, but does not factor in changes in agricultural pests and the possible effect of changing climatic variability.

Computer models predict that temperate forests in the western U.S. might be displaced by dryer forest habitats, but impacts on the production of temperate forest products are expected to be relatively small. For fishery resources, the beneficial effects of climate change such as longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships.

Reduced glaciers and snow cover would affect the seasonal distribution of river flow and water supply for hydroelectric generation and agriculture. A rise in sea level and changes in storms or storm surges could result in the erosion of coastal shores and increased coastal flooding.

Increased climatic variability associated with an increase in atmospheric greenhouse gases may be the major disruptive hazard facing Montana in the long term. Climatologists have predicted that a greenhouse climate will not only be warmer, but more prone to heavy rainstorms, drought and changing storm patterns (Kerr, 1995). An increase in extreme weather patterns (floods, droughts, wildfires, tornadoes and hurricanes) would have a detrimental effect on Montana's farmers, hydropower suppliers, insurance industry, and others. A higher risk of extreme climate events due to climate change could lead to higher insurance premiums or the withdrawal of coverage for property in some vulnerable areas.

VI. Greenhouse Gases

A. Carbon Dioxide

Carbon dioxide is the primary greenhouse gas produced by human activity. Scientists estimate that 85 percent of the U.S. contribution to global warming is from carbon dioxide (DOE/EIA, 1995). The combustion of fossil fuels such as coal, natural gas, and petroleum is the major anthropogenic source of carbon dioxide, producing about 98.5 percent of carbon dioxide emissions nationwide (EPA, 1994). Non-energy production processes, such as lime and cement production, timber harvesting and slash burning, also emit carbon dioxide.

Carbon dioxide emissions can be estimated more reliably than any other greenhouse gas because fossil fuels are of considerable economic value and their consumption is carefully monitored. Scientists believe that the estimate of the amount of carbon dioxide emitted from fossil fuels is accurate to within 5 percent.

B. Methane

Methane is estimated to be responsible for about 11 percent of the total carbon dioxide equivalent greenhouse gas emissions in the U.S. (DOE/EIA, 1995). Most methane is produced through anaerobic decomposition of organic matter, with landfills the largest single source of methane in the U.S. Methane is also emitted during the production and distribution of natural gas and oil, and as a byproduct of coal mining. Methane emission estimates are much more uncertain than carbon dioxide estimates because of a lack of data. Methane emissions are unintended side-effects of energy production and use, municipal waste disposal and animal husbandry and are only rarely metered as in the case of underground coal mines.

C. Nitrous Oxide

Nitrous oxide emissions contribute about 2 percent of the total carbon dioxide equivalent emissions in the U.S. (DOE/EIA, 1995). Anthropogenic sources of nitrous oxide emissions include the use of nitrogen fertilizers and fossil fuel combustion. However, estimates of nitrous oxide emissions from nitrogen fertilizer use is reliable only within an order of magnitude due to the site-specific nature of emission factors and lack of detailed information. Emission data from fossil fuel use, mainly transportation, are thought to be under estimated because of unreliable sampling methods.

D. Halocarbons and Minor Gases

Human-made halocarbons such as halogenated fluorocarbons (HFC's), perfluorinated carbons (PFC's) and other minor gases are emitted in smaller volumes than the other greenhouse gases, but cause the absorption of disproportionate amounts of infrared radiation. The GWP of these compounds range from hundreds to thousands of times that of carbon dioxide. These compounds are used as refrigerants, propellants and solvents and remain trapped for a decade or more, leak out of the equipment within a few years, or are released directly to the atmosphere. CFC's and several other chemicals are regulated as ozone-depleting substances and are being phased out of U.S. production and use. Substitute chemicals such as hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) are much less damaging to stratospheric ozone, but scientists believe that they may have a stronger effect on global climate.

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Chapter 2. Energy Related Emissions

I. Summary

Montana relies on a variety of fuels to satisfy its energy needs, mainly fossil fuels and hydroelectric generation and to a lesser extent biofuels, solar and wind power. Fossil fuels are the primary source of energy and include petroleum, coal and natural gas. Fuel combustion in a boiler, furnace, or engine converts carbon in the fuel to carbon dioxide (CO_2).

Sources of energy related greenhouse gas emissions are divided into four categories:

1) fossil and biomass fuel combustion,
2) coal mining,
3) oil and natural gas production, refining and distribution, and
4) interstate energy transfers.

Estimates of carbon dioxide emissions are made for fossil and biomass fuel combustion, and estimates of methane emissions are made for coal mining and oil and natural gas systems. Emissions from fossil and biomass fuel combustion are further subdivided into end use sectors: residential, commercial, industrial, transportation, and utilities.

Greenhouse gas emissions were estimated for total fuel used to satisfy Montana's energy needs in 1990. The EPA State Workbook (1995) recommends separate reporting for emissions due to fuel mined and processed in Montana but exported and consumed out of state. Emissions from fuel imported into Montana also are reported separately. Emissions from coal mined and burned in Montana to produce electricity for transmission and use out of state also are reported independently under the interstate transfer section of this chapter. They are not included in State totals of greenhouse gas emission estimates.

Total carbon dioxide equivalent emissions from the energy sector in Montana in 1990 was 21,408,699 tons. Carbon dioxide emissions from fossil fuel combustion in 1990 totaled approximately 21,068,891 tons while carbon dioxide emissions from biomass fuel combustion totaled about 37,282 tons.

Methane emissions from natural gas and oil systems totaled about 11,572 tons with about 776 tons from coal mining. The global warming potential for methane is 24.5 times that of carbon dioxide, meaning that a molecule of methane has 24.5 times the effect on climate that one molecule of carbon dioxide has. Therefore, greenhouse gas emissions from natural gas and oil systems are equivalent to about 283,514 tons of carbon dioxide, and emissions from coal mining are equivalent to about 19,012 tons of carbon dioxide. Figure 2.1 and Table 2.1

Greenhouse gas emissions from the energy sector can also be broken down by fuel type; coal, petroleum, natural gas, and biomass; and reported in terms of carbon dioxide equivalent.

Figure 2.1. Energy Related Emissions in Carbon Dioxide Equivalent by Activity.

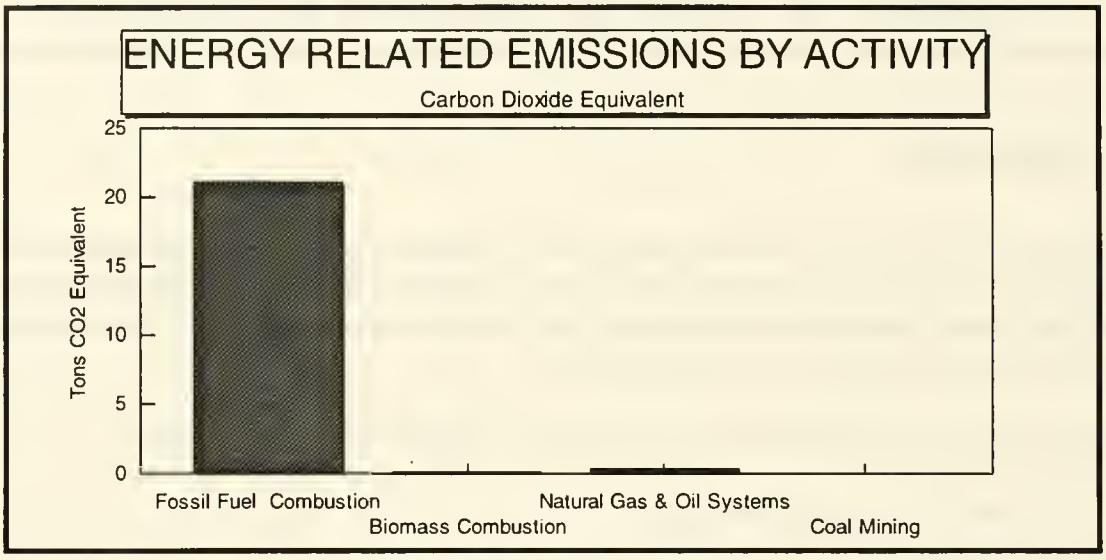


Table 2.1. Energy Related Emissions in Carbon Dioxide Equivalent by Activity.

ENERGY RELATED EMISSIONS BY ACTIVITY Tons of Carbon Dioxide Equivalent	
Fossil Fuel Combustion	21,068,891
Biomass Combustion	37,282
Natural Gas & Oil Systems	283,514
Coal Mining	19,012
Total	**21,408,699**

Greenhouse gas emissions from coal used to satisfy Montana's energy needs include carbon dioxide from coal combustion and methane from coal mining activities. Approximately 7,284,607 tons of carbon dioxide equivalent emissions resulted from coal combustion and mining to produce energy for use in Montana in 1990.

Emissions from petroleum production and use include carbon dioxide from the combustion of numerous petroleum products and methane from the production, refining and storage of crude oil. Approximately 11,303,243 tons of carbon dioxide equivalent emissions resulted from petroleum production and use in Montana in 1990.

Emissions from natural gas include carbon dioxide from the combustion of natural gas for electric generation and methane from natural gas production, processing, transport and distribution. Approximately 2,783,567 tons of carbon dioxide equivalent emission resulted from natural gas production and use in Montana in 1990.

Emissions from biomass includes carbon dioxide from the combustion of both wood and ethanol for energy purposes. Wood accounts for about 37 percent of the emissions and ethanol in gasohol for the remaining 63 percent. Approximately 37,282 tons of carbon dioxide emissions resulted from biomass combustion for energy use in Montana in 1990. Emissions by fuel type are presented in Figure 2.2 and Table 2.2.

Figure 2.2. Energy Related Emissions in Carbon Dioxide Equivalent by Fuel Type.

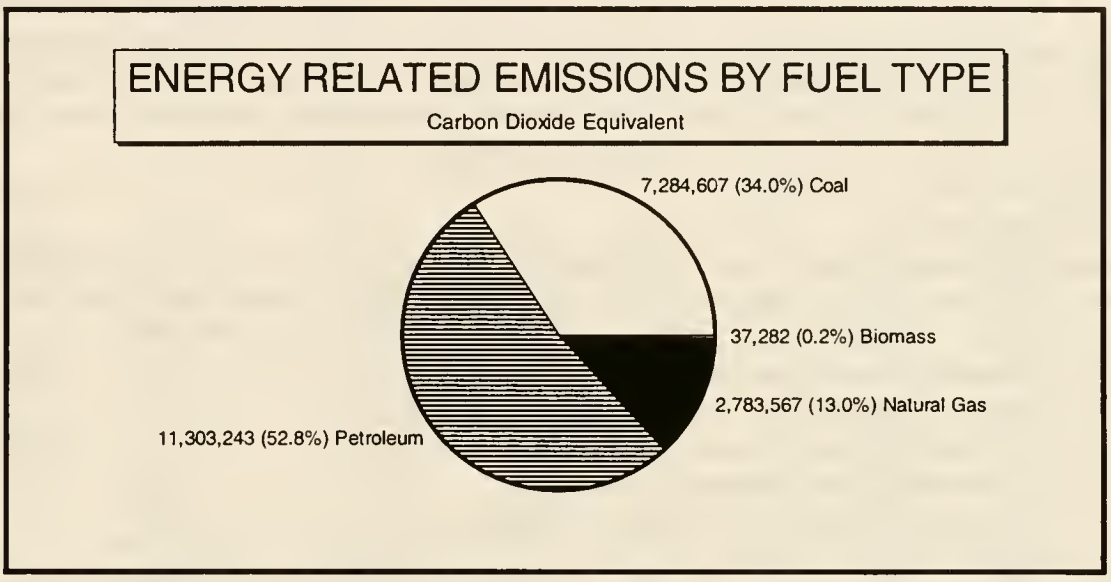


Table 2.2. Energy Related Emissions in Carbon Dioxide Equivalent by Fuel Type.

ENERGY RELATED EMISSIONS BY FUEL TYPE Tons of Carbon Dioxide Equivalent	
Coal	7,284,607
Petroleum	11,303,243
Natural Gas	2,783,567
Biomass	37,282
Total	**21,408,699**

II. Fossil and Biomass Fuel Combustion

A. Background

Fossil fuels include coal, oil, and natural gas. Fossil fuel combustion produces the vast majority of energy related emissions in Montana. These emissions are produced from a variety of fossil fuel combustion

activities in Montana, including heating in residential and commercial buildings, coal combustion to generate electricity, and gasoline consumption in automobiles and other vehicles. Lesser amounts of carbon dioxide are emitted during combustion of biomass fuels such as wood and ethanol.

As fuels burn, they emit carbon dioxide as a result of oxidation of the carbon in the fuel. The amount of carbon dioxide emitted from fuel combustion relates directly to the type and amount of fuel consumed, the fraction of the fuel that is oxidized, and the carbon content of the fuel. Coal has the highest carbon content of fossil fuels. Oil has approximately 80 percent as much carbon content as coal, and natural gas about 60 percent, on an energy equivalent basis (Wuebbles and Edmonds, 1993). Not all carbon in fuel products is oxidized to carbon dioxide because inefficiencies in the combustion process leaves some carbon unburned. In addition, some fossil fuel materials are used in the manufacture of products, such as road asphalt, where the carbon is stored in the product. These carbon-containing products are considered a carbon sink and the carbon they contain is not included in estimates of greenhouse gas emissions.

B. Methodology

The methodology used to compute carbon dioxide emissions follows the approach provided in the State Workbook (EPA, 1995). In order to arrive at emission estimates, the following factors were considered:

- amount of each type of fossil fuel consumed,
- amount of biomass (wood and ethanol) consumed,
- amount of carbon in each fuel type,
- amount of carbon stored in products, and
- amount of carbon oxidized during combustion.

Fossil and biomass fuel consumption estimates for each sector (residential, commercial, industrial, transportation, and utilities) were obtained for Montana from national data sources. We assumed that international bunker fuels (fuels used in international transportation) were insignificant for Montana. Therefore this small amount of fuel was not identified and not subtracted from total state fuel consumption estimates.

Physical units of fuel consumptions were converted to British thermal units (Btu) using conversion factors provided in the State Workbook (EPA, 1995), except for coal for which state-specific data were available. Montana coal averages 9,012 Btu/lb (DOE/EIA, 1991A), so the conversion factor from tons of coal to million Btu is 18.024 for Montana rather than 17.14 as listed in the State Workbook.

The amount of fuel consumed for each energy type per sector was next multiplied by the carbon content coefficient to estimate the total carbon that could be released from the combustion. The carbon content coefficient represents the amount of carbon emitted per unit of energy obtained by burning a specific type of fuel. Carbon content coefficients vary considerably both between and within major fuel types. Carbon content coefficients were provided by the Energy Information Administration of the U.S. Department of Energy and presented in the State Workbook (EPA, 1995.)

The amount of carbon stored in noncombusted products made from fossil fuel materials was subtracted from total fuel consumption estimates. For inventory estimates, the EPA Workbook assumed that products that store or sequester carbon are limited to the industrial sector and include products like road asphalt and lubricants.

The amount of net carbon was multiplied by the fraction oxidized (99 percent except for wood which is assumed to oxidize less completely at 90 percent). Finally, net carbon was multiplied by the molecular weight ratio (44/12) to determine carbon dioxide emissions on a molecular weight basis. Table 2.3 details the method used to calculate carbon dioxide emissions from fossil and biomass fuel combustion for all fuel sources. Table 2.4 summarizes emission calculations for coal, natural gas, and petroleum fuel types for each economic sector. Carbon dioxide emissions from biomass fuels are reported separately in the table.

Table 2.3. Carbon Dioxide Calculations and Emissions by Fuel Type and Source, All Sectors.

		(A) Input Consumption (MBtu)	(B) Assumption Carbon Content Coefficient (lbsC/MBtu)	(AxB)=C Calculated Total Carbon (tons C)	(D) Adjustment Stored Carbon (tons C)	(C-D)=E Calculated Net Carbon (tons C)	(Ex.99 or.9)=F Calculated Total C Oxidized (tons C)	(Fx44/12)=G Calculated CO_2 Emissions (tons CO_2)
RESIDENTIAL								**Total 1,409,258**
Coal	Sub-Bituminous	341,704	57.90	9,892	0	9,892	9,793	35,909
Natural Gas		17,355,500	31.90	276,820	0	276,820	275,436	1,009,932
Petroleum	Distillate Fuel Oil	1,679,327	44.00	36,945	0	36,945	36,576	134,111
	Kerosene	6,345	43.50	138	0	138	137	501
	Liquefied Petroleum Gas	3,261,206	37.80	61,637	0	61,637	61,020	223,742
Biomass	Wood (lbs)	6,460,000	0.48	1,534	0	1,534	1,381	5,063
COMMERCIAL								**Total 946,471**
Coal	Sub-Bituminous	634,592	57.90	18,371	0	18,371	18,188	66,688
Natural Gas		12,528,920	31.90	199,836	0	199,836	198,837	729,069
Petroleum	Distillate Fuel Oil	891,225	44.00	19,607	0	19,607	19,411	71,173
	Kerosene	675	43.50	15	0	15	15	53
	Liquefied Petroleum Gas	575,507	37.80	10,877	0	10,877	10,768	39,484
	Motor Gasoline	436,963	42.80	9,351	0	9,351	9,258	33,944
	Residual Fuel Oil	69,554	47.40	1,648	0	1,648	1,632	5,984
Biomass	Wood (lbs)	95,500	0.48	23	0	23	20	75
INDUSTRIAL								**Total 5,485,399**
Coal	Sub-Bituminous	3,768,160	57.90	109,088	0	109,088	107,997	395,990
Natural Gas		12,036,580	31.90	191,983	0	191,983	191,024	700,420
Petroleum	Asphalt & Road Oil	9,869,069	45.50	224,521	222,276	2,245	2,223	8,150
	Aviation Gasoline	2,215	41.60	46	0	46	46	167
	Distillate Fuel Oil	16,011,788	44.00	352,259	0	352,259	348,737	1,278,701
	Kerosene	38,880	43.50	846	0	846	837	3,070
	Liquefied Petroleum Gas	2,873,839	37.80	54,316	43,018	11,298	11,185	41,010
	Lubricants	317,306	44.60	7,076	3,481	3,595	3,559	13,048
	Motor Gasoline	3,711,046	42.80	79,416	0	79,416	78,622	288,281
	Petroleum Coke	14,810,292	61.40	454,676	0	454,676	450,129	1,650,474
	Residual Fuel Oil	1,313,983	47.40	31,141	0	31,141	30,830	113,043
	Still Gas (refinery gas)	13,753,382	38.60	265,440	0	265,440	262,786	963,548
Biomass	Wood (lbs)	11,192,500	0.48	2,658	0	2,658	2,392	8,772
	Ethanol	273,148	41.80	5,709	0	5,709	5,652	20,723
TRANSPORTATION								**Total 6,443,592**
Natural Gas		2,112,530	31.90	33,695	0	33,695	33,526	122,930
Petroleum	Aviation Gasoline	564,974	41.60	11,751	0	11,751	11,634	42,658
	Distillate Fuel Oil	24,285,242	44.00	534,275	0	534,275	528,933	1,939,419
	Jet Fuel: Kerosene	2,839,645	43.50	61,762	0	61,762	61,145	224,197
	Jet Fuel: Naptha	1,108,085	43.50	24,101	0	24,101	23,860	87,486
	Liquefied Petroleum Gas	269,544	37.80	5,094	0	5,094	5,043	18,493
	Lubricants	1,219,123	44.60	27,186	0	27,186	26,915	98,687
	Motor Gasoline	50,295,736	42.80	1,076,329	0	1,076,329	1,065,565	3,907,073
Biomass	Ethanol	34,912	41.80	730	0	730	722	2,649
ELECTRIC UTILITIES								**Total 6,821,453**
Coal	Sub-Bituminous	64,393,415	57.90	1,864,189	0	1,864,189	1,845,547	6,767,007
Natural Gas		430,162	31.90	6,861	0	6,861	6,827	25,032
Petroleum	Distillate Fuel Oil	368,321	44.00	8,103	0	8,103	8,022	29,414

Table 2.4. Carbon Dioxide Calculations and Emissions from all Sectors for Coal, Natural Gas and Petroleum.

	Input Consumption (MBtu)	Calculated Total Carbon (tons C)	Adjustment Stored Carbon (tons C)	Calculated Net Carbon (tons C)	Calculated Total C Oxidized (tons C)	Calculated CO_2 Emissions (tons CO_2)
Residential	22,644,081	385,433	0	385,433	382,962	**Total 1,404,195**
Coal	341,704	9,892	0	9,892	9,793	35,909
Natural Gas	17,355,500	276,820	0	276,820	275,436	1,009,932
Petroleum	4,946,877	98,720	0	98,720	97,733	358,354
Commercial	15,137,436	259,706	0	259,706	258,108	**Total 946,396**
Coal	634,592	18,371	0	18,371	18,188	66,688
Natural Gas	12,528,920	199,836	0	199,836	198,837	729,069
Petroleum	1,973,924	41,498	0	41,498	41,083	150,638
Industrial	78,506,539	1,770,810	268,775	1,502,034	1,487,974	**Total 5,455,904**
Coal	3,768,160	109,088	0	109,088	107,997	395,990
Natural Gas	12,036,580	191,983	0	191,983	191,024	700,420
Petroleum	62,701,799	1,469,738	268,775	1,200,963	1,188,953	4,359,494
Transportation	82,694,879	1,774,194	0	1,774,194	1,756,621	**Total 6,440,943**
Coal	0	0	0	0	0	0
Natural Gas	2,112,530	33,695	0	33,695	33,526	122,930
Petroleum	80,582,349	1,740,499	0	1,740,499	1,723,094	6,318,013
Electric Utilities	65,191,898	1,879,154	0	1,879,154	1,860,396	**Total 6,821,453**
Coal	64,393,415	1,864,189	0	1,864,189	1,845,547	6,767,007
Natural Gas	430,162	6,861	0	6,861	6,827	25,032
Petroleum	368,321	8,103	0	8,103	8,022	29,414
Total	264,174,833	6,069,296	268,775	5,800,520	5,746,061	**Total 21,068,891**
Coal	69,137,871	2,001,541	0	2,001,541	1,981,526	7,265,595
Natural Gas	44,463,692	709,196	0	709,196	705,650	2,587,383
Petroleum	150,573,270	3,358,559	268,775	3,089,783	3,058,885	11,215,913
Biomass	18,056,060	10,654	0	10,654	10,168	**Total 37,282**
Wood	17,748,000	4,215	0	4,215	3,794	13,910
Ethanol	308,060	6,438	0	6,438	6,374	23,372

C. Data Sources

Fossil fuel consumption for each end use sector is published by The Department of Energy (DOE/EIA, 1995). However, the published data are rounded to the nearest thousand tons for coal, billion cubic feet for natural gas, and thousand barrels for petroleum products. Therefore, specific consumption values for Montana in physical units for 1990 were requested and transmitted by fax from Roy Stanley (1996). The breakdown of electric utility data to end use sectors was from the Electric Power Annual 1990 (DOE/EIA, 1992).

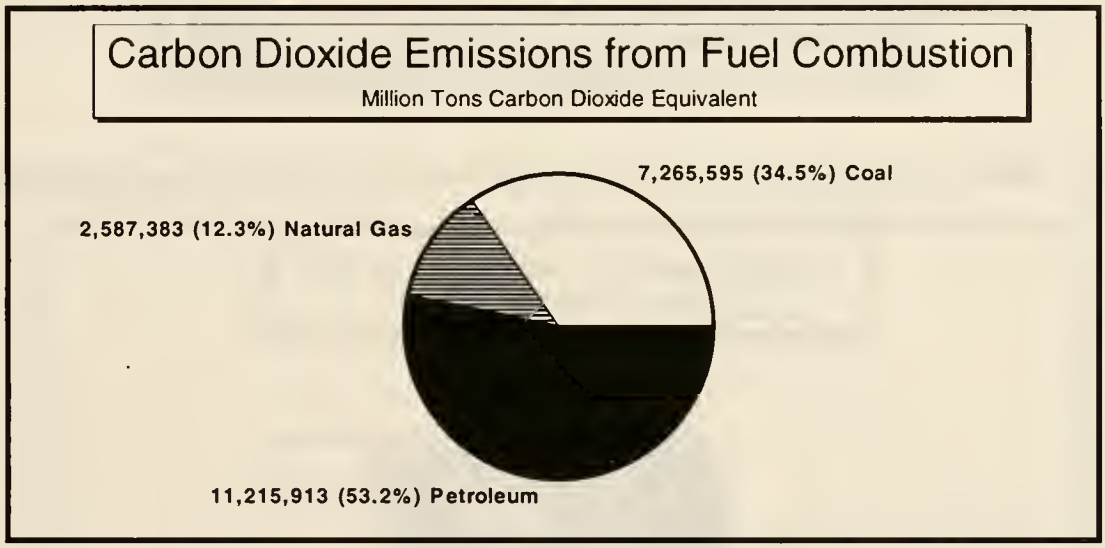
Coal data for the residential, commercial, industrial, and utility sectors are from Consumption Estimates State Energy Data Report (DOE/EIA, 1995) and Montana Energy Data Report (MEQC and MDNRC, 1993).

Biomass data for ethanol use in the transportation sector are from Montana Energy Data Report (MEQC and MDNRC, 1993). Biomass data for wood use in the commercial, industrial and residential sectors are from an unpublished report by Howard Haines (MDNRC, 1991).

D. Emissions Results

Total carbon dioxide emissions from the combustion of fossil fuel in Montana in 1990 was about 21.1 million tons. Coal combustion accounts for about 35 percent (7.3 million tons), natural gas combustion about 12 percent (2.6 million tons) and petroleum about 53 percent (11.2 million tons). Figure 2.3.

Figure 2.3. Carbon Dioxide Emissions From Each Fuel Type.


Carbon Dioxide Emissions from Fuel Combustion
Million Tons Carbon Dioxide Equivalent
7,265,595 (34.5%) Coal
2,587,383 (12.3%) Natural Gas
11,215,913 (53.2%) Petroleum

Carbon dioxide emissions for each economic sector are illustrated in two different ways. The first looks at electricity generation as a separate sector. The second is with the emissions due to electricity use added to each sector according to their respective end uses. This was done because electricity is not a fuel and the production of fossil-based electricity is a major contributor to emissions. In Montana, 99.7 percent of carbon dioxide emissions from electric generation are derived from coal. Natural gas and petroleum fuels contribute about 0.15 percent each to electric generation based carbon dioxide emissions. Unlike other fuel sources, emissions from electric generation do not occur at the point of use but at the electric generation site. Emissions from the combustion of biomass fuels are not included in these totals.

The State Workbook (EPA, 1995) recommends reporting biomass fuels separately. Total carbon dioxide emissions from the combustion of biomass fuels in 1990 were 37,282 tons, less than 0.1 percent of the total amount from fuel combustion in the energy sector. Wood combustion for energy purposes produced

about 37 percent of biomass emissions (14 thousand tons) and ethanol about 63 percent (23 thousand tons).

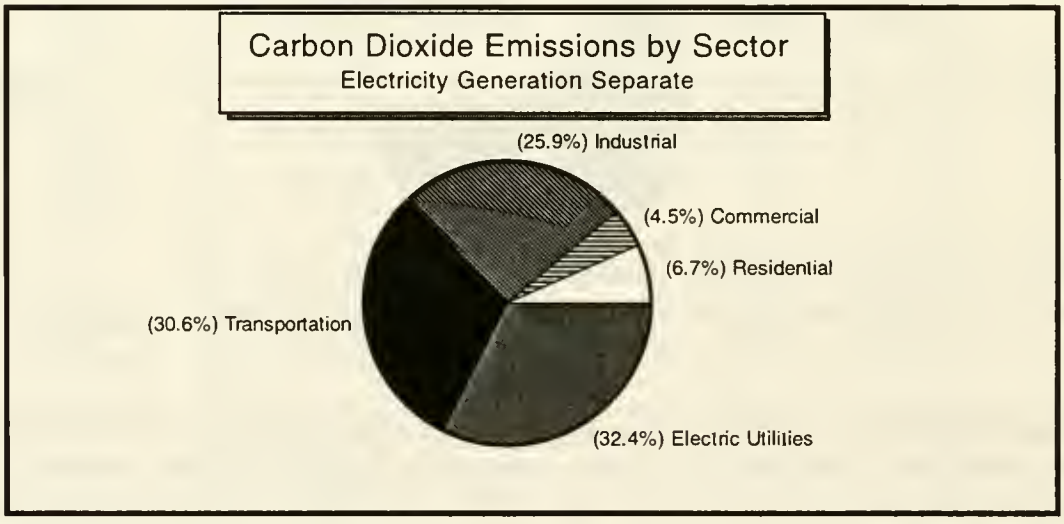
Electric Generation Reported as a Separate Sector

When electricity generation is considered separately, results reveal that about one-third of all carbon dioxide emissions from fuel combustion are from the electric utility sector. Figure 2.4 and Table 2.5. Agricultural use of natural gas is reported in the commercial sector rather than the industrial sector.

Table 2.5. Electric Generation Separate Sector.

Sector	Million Tons CO_2	Percent of Total
Residential	1.4	6.7
Commercial	0.9	4.5
Industrial	5.5	25.9
Transportation	6.4	30.6
Electric Utility	6.8	32.4
Total	21.1	100.0

Figure 2.4. Carbon Dioxide Emissions for each Economic Sector with Electricity Generation Separate.



This data were further broken down by fuel type; coal, natural gas, and petroleum, as identified in Table 2.6 and Figure 2.5. Coal-based electric generation contributes the greatest amount to carbon dioxide emissions while petroleum use in the transportation and industrial sectors are the second and third largest contributors.

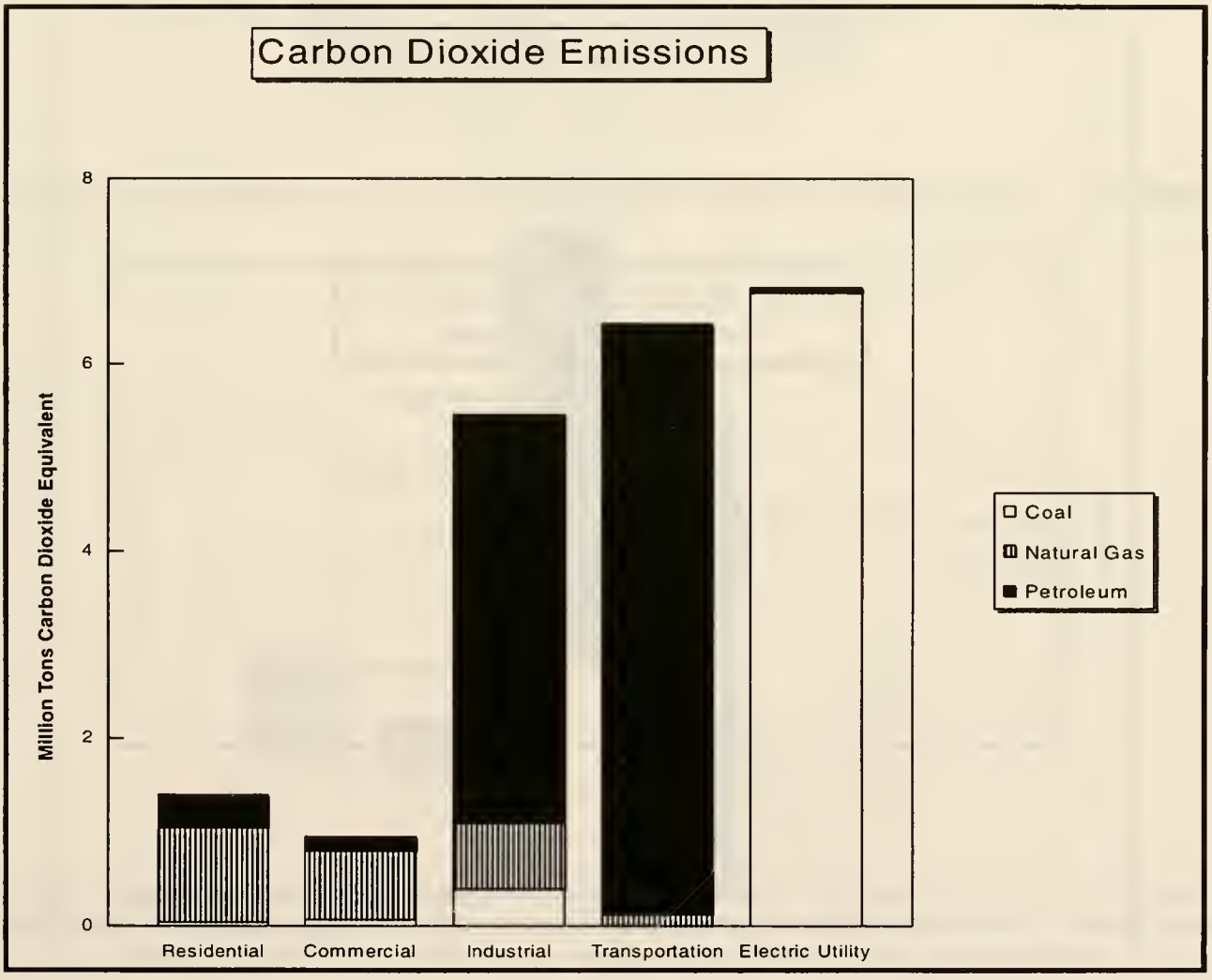
Economic sector data presented with electric generation reported as a separate sector can be misleading because they do not assign carbon dioxide emissions to their end use. The next section and further discussions distribute emissions due to electric generation among users.

Table 2.6. Carbon Dioxide Emissions by Economic Sector with Electricity Distributed Among Users.

Carbon Dioxide Emissions
Tons Carbon Dioxide Equivalent

	Coal	Natural Gas	Petroleum	Total
Residential	35,909	1,009,932	358,354	1,404,195
Commercial	66,688	729,070	150,638	946,396
Industrial	395,990	700,420	4,359,494	5,455,904
Transportation	0	122,930	6,318,013	6,440,943
Electric Utility	6,767,007	25,032	29,414	6,821,453
Total	7,265,594	2,587,384	11,215,913	21,068,891

Figure 2.5. Emissions of Carbon Dioxide from Fuel Combustion. Electric Generation Separate Sector.



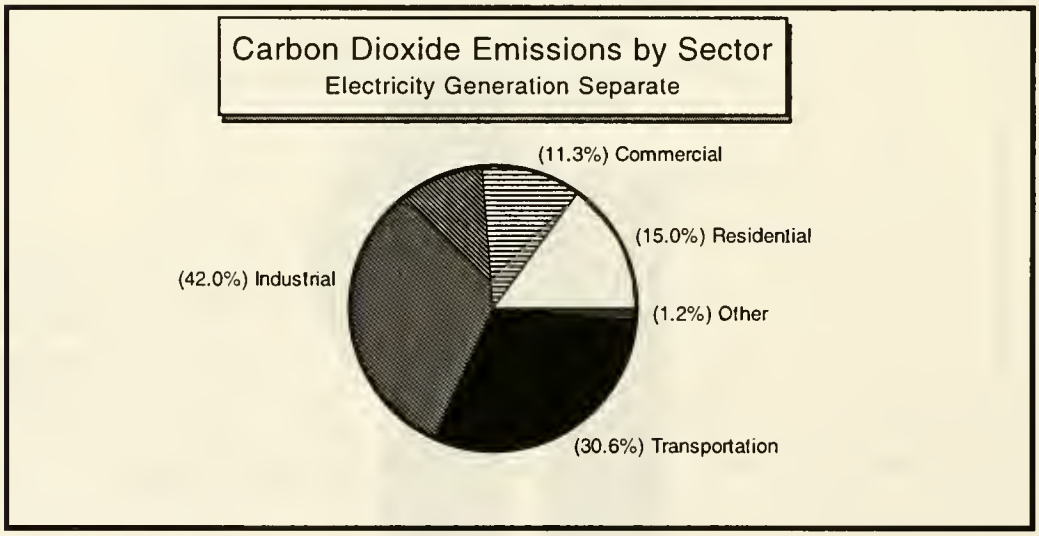
Electric Generation Distributed Among Users

To more accurately portray greenhouse gas emissions resulting from different use sectors, emissions from electric energy generation were distributed among users in the residential, commercial, industrial and other sectors. This distribution was accomplished by using data on electric utility sales to ultimate consumers by sector for Montana in 1990 (DOE/EIA, 1992). Emissions resulting from coal burned for electric generation were added to emissions from other sources and are reported in Table 2.7 and Figure 2.6. The other sector as defined in the EIA State Energy Data report includes public street and highway lighting, other sales to public authorities, sales to railroads, and interdepartmental sales.

Table 2.7. Electric Generation Included.

Sector	Million Tons CO_2	Percent of Total
Residential	3.2	15.0
Commercial	2.4	11.3
Industrial	8.8	42.0
Transportation	6.4	30.6
Other	0.3	1.2
Total	21.1	100.0

Figure 2.6. Carbon Dioxide Emissions by Economic Sector with Electricity Distributed Among Users.



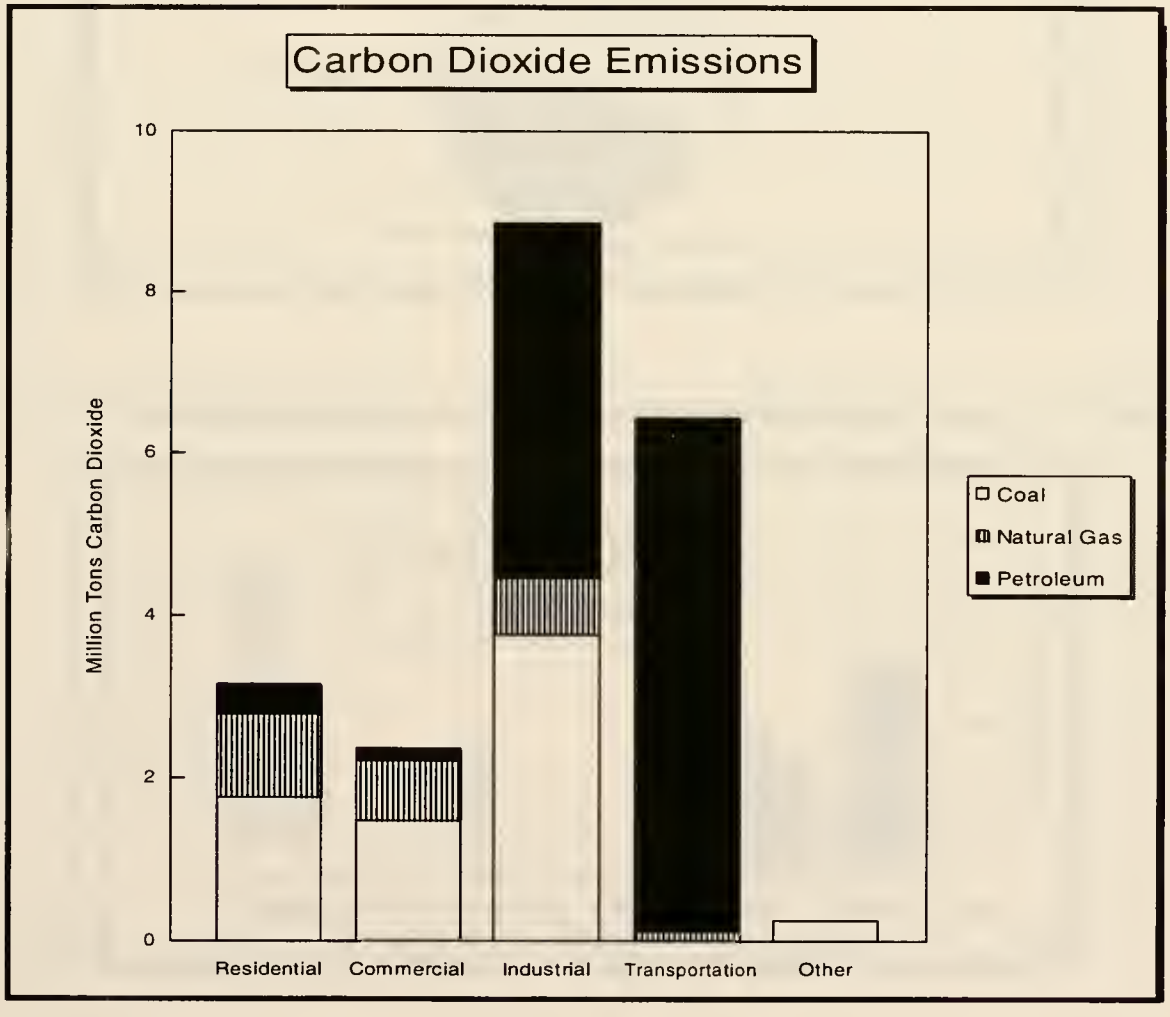
These data were further broken down by fuel type; coal, natural gas, and petroleum, as identified in Table 2.8 and Figure 2.7. These data show that the industrial sector contributes the largest amount of carbon dioxide emissions among all the economic sectors in Montana.

Table 2.8. Emissions of Carbon Dioxide from Fuel Combustion. Electric Generation Distributed Among Users.

Carbon Dioxide Emissions
Tons Carbon Dioxide Equivalent

	Coal	Natural Gas	Petroleum	Total
Residential	1,768,263	1,016,340	365,884	**3,150,487**
Commercial	1,480,992	734,301	156,786	**2,372,079**
Industrial	3,759,193	712,862	4,374,112	**8,846,167**
Transportation	0	122,930	6,318,013	**6,440,943**
Other	257,146	951	1,118	**259,215**
Total	**7,265,594**	**2,587,384**	**11,215,913**	**21,068,891**

Figure 2.7. Emissions of Carbon Dioxide from Fuel Combustion. Electric Generation Distributed Among Users.



Commercial Sector

The commercial sector in Montana includes all non-industrial companies, such as retail stores, offices, restaurants and warehouses. It also includes the agricultural component of energy use. Carbon dioxide emissions from the commercial sector totaled 2.4 million tons in 1990. Approximately 62 percent of the carbon dioxide emissions (1.5 million tons) are from coal-based electricity use, 31 percent from natural gas, and about 7 percent from petroleum. (Figure 2.10). A breakdown of carbon dioxide emissions from specific fuel sources is provided in Figure 2.11.

Figure 2.10. Carbon Dioxide Emissions from Fossil Fuel Combustion by the Commercial Sector.

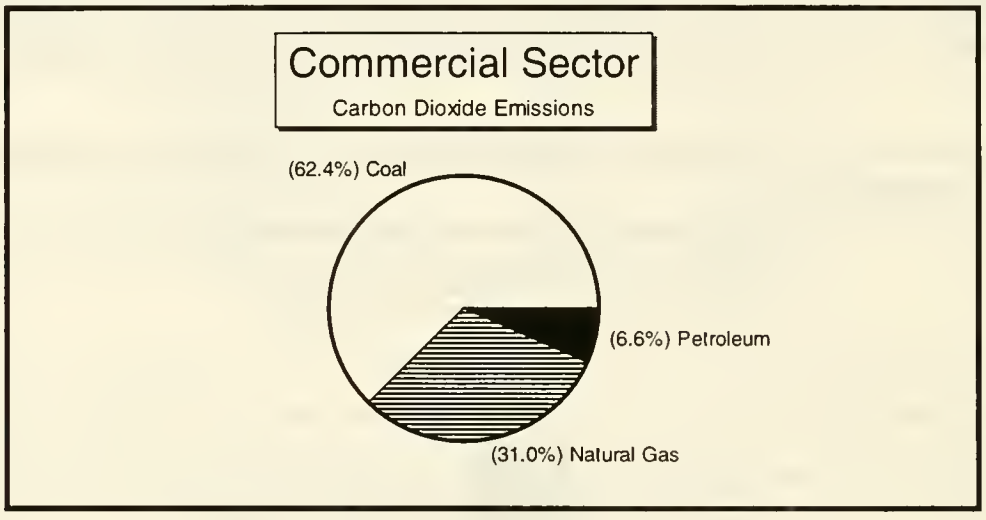
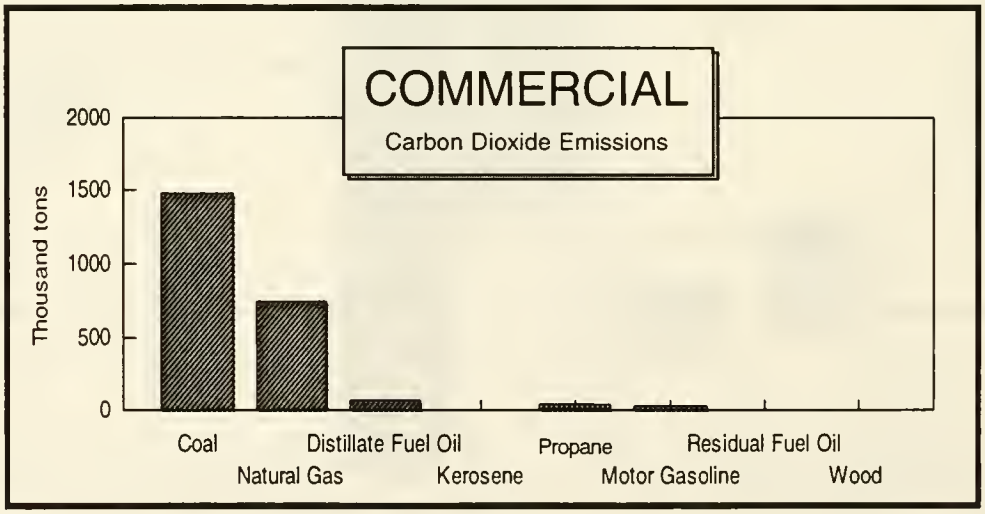


Figure 2.11. Carbon Dioxide Emissions for each Fuel in the Commercial Sector.



Industrial Sector

Carbon dioxide emissions from Montana's industrial sector total about 8.8 million tons. The industrial sector is made up of a variety of mining, smelting, manufacturing and construction industries. Petroleum products produce the largest portion of carbon dioxide emissions at about 49 percent of total industrial emissions, chiefly from petroleum coke, distillate fuel, still gas, motor gas and residual fuel. Coal based electricity emissions totaled about 3.7 million tons (43 percent). Natural gas generates about 8 percent of carbon dioxide emissions from the industrial sector. (See Figure 2.12 and Figure 2.13). Petroleum products identified in Figure 2.13 are defined by DOE/EIA in the State Energy Data Report (1995).

Figure 2.12. Carbon Dioxide Emissions from Fossil Fuel Combustion by the Industrial Sector.

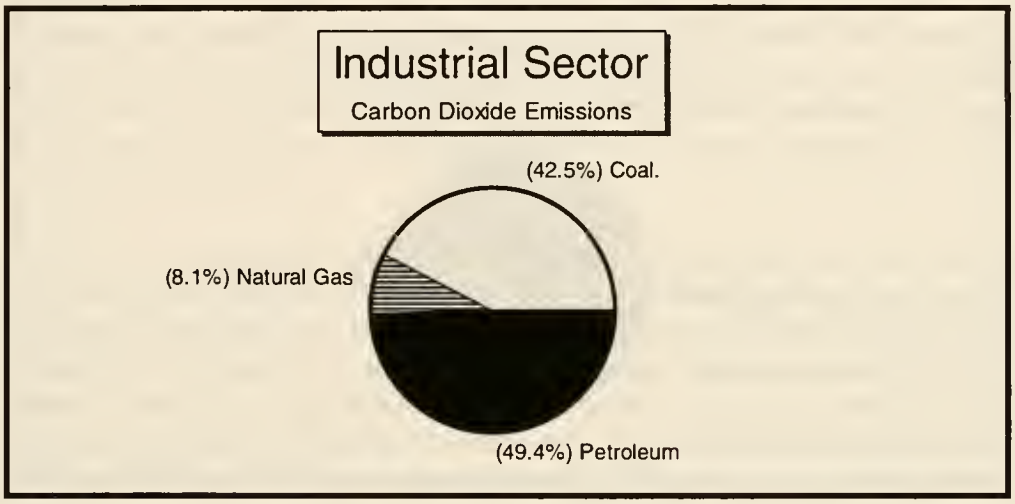
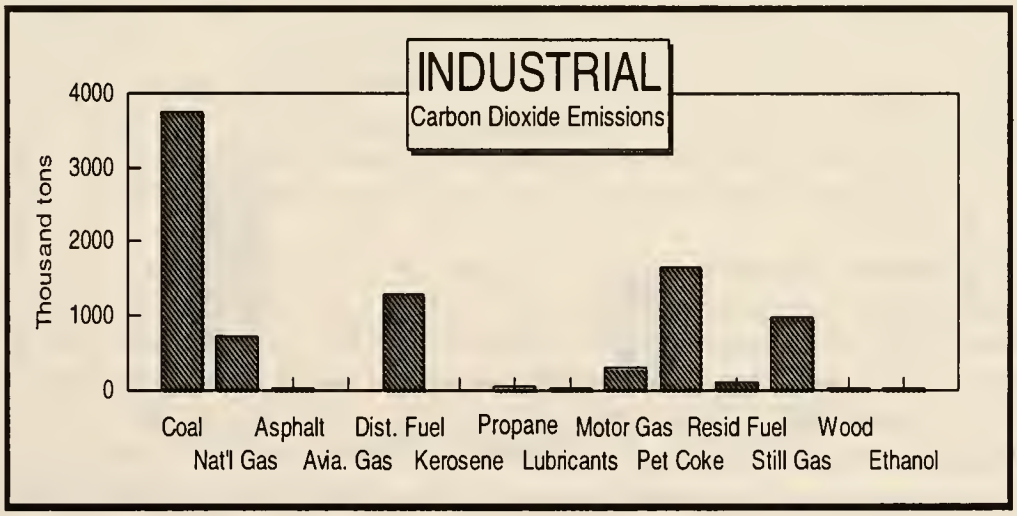


Figure 2.13. Carbon Dioxide Emissions for each Fuel in the Industrial Sector.



Transportation Sector

Petroleum based fuels contribute about 98 percent of the total emissions from the transportation sector (Figure 2.14). This contrasts with the other economic sectors, in which coal-based electric generation was the largest source of carbon dioxide emissions. Specific petroleum based fuels and their respective carbon dioxide emission totals are identified in Figure 2.15. Distillate fuel oil includes on- and off-highway diesel engine fuel, including railroad engine fuel and fuel for agricultural machinery.

Figure 2.14. Carbon Dioxide Emissions from Fossil Fuel Combustion by the Transportation Sector.

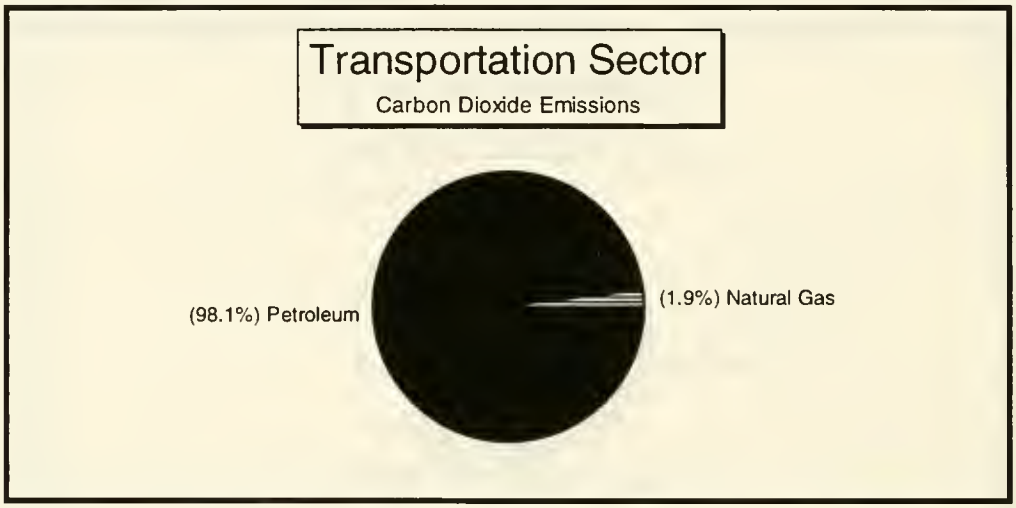
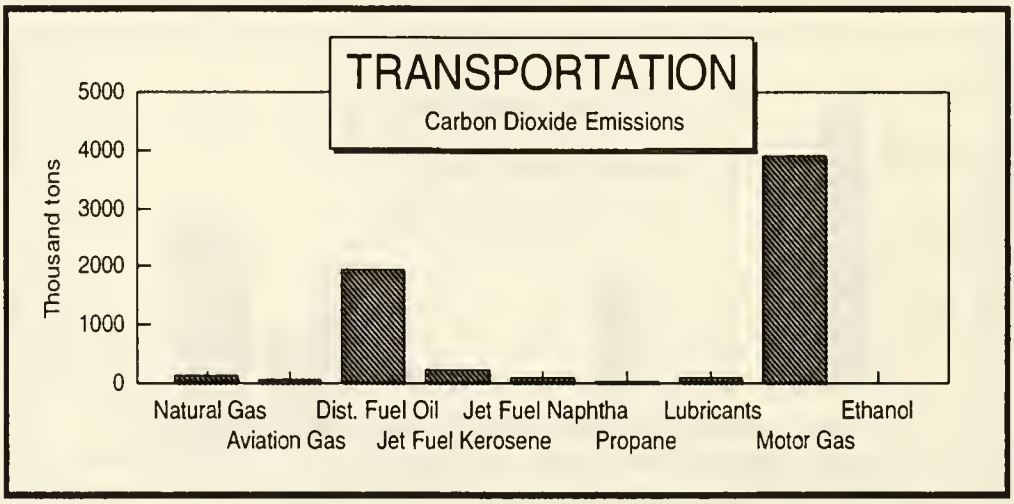


Figure 2.15. Carbon Dioxide Emissions for each Fuel in the Transportation Sector.



Other Electric Generation

The DOE/EIA State Energy Data Report (1995) defines "other" electric generation to include the category of electric generation for the end uses of public street and highway lighting, sales to railroads, and interdepartmental sales as defined in the Electric Power Annual (DOE/EIA, 1992). Emissions from the "other" electric generation category total about 645,000 tons of carbon dioxide with more than 99 percent from coal-based electric generation.

III. Natural Gas and Oil Systems

A. Background

Methane emissions occur throughout the total fuel cycles of natural gas and oil. For natural gas systems, methane emissions occur during field production, processing, refining, and storage. Fugitive methane emissions also occur from venting and flaring of natural gas at the wellhead and from leaks in transmission and distribution systems. For petroleum liquids, methane emissions occur during field production, refining, and storage.

Oil and gas systems are divided into three main categories for this analysis. The first, oil and gas production, includes the process and equipment used in withdrawing oil and gas from wells. Often, oil and gas are withdrawn simultaneously from the same geologic formation and then separated. Gathering lines are generally used to bring the crude oil and raw gas to collection points within a production field. Because methane is the major component of natural gas, leaks or venting from these systems results in methane emissions. Montana's 270 active oil fields produced about 19.8 million barrels of oil in 1990. The 195 active gas fields in Montana produced about 51.5 billion cubic feet of natural gas in 1990 (MDNRC, 1991).

The second major category is crude oil transportation and refining. Crude oil is transported by pipeline to tankers and refineries. Often, the crude oil is stored in tanks for a period of time. Methane is usually found in the crude oil stream, and leaks or venting of vapors from these facilities result in methane emissions, particularly from crude oil tankering. Montana has four crude oil refineries and refined about 47.5 million barrels in 1990. About 8.5 percent (4 million barrels) of the crude oil received was from Montana, about 57 percent (27.3 million barrels) from Canada and about 34 percent (16.4 million barrels) from Wyoming (MDNRC Board of Oil and Gas Conservation, 1991). About 15.8 million barrels of oil produced in Montana were shipped out of state for refining elsewhere.

The final category is natural gas processing, transportation and distribution. Natural gas is processed to recover heavier hydrocarbons, such as ethane, propane and butane, and dried gas prepared for transporting to consumers. High pressure lines transport gas from production fields, processing plants, storage facilities, and other supply sources over long distances to distribution centers, or large volume customers. Distribution pipelines are extensive networks of generally small diameter, low pressure pipelines. Gas enters distribution networks from transmission systems where the pressure is reduced for distribution within cities or towns.

B. Methodology

In estimating methane emissions from oil and natural gas systems we followed the methods described in the EPA State Workbook (1995). The first step was to convert production data to energy units of million Btu (MMBtu) as follows:

Oil and Gas Production
Oil production in Montana in 1990:
19,835,087 barrels x 5.825 MMBtu/barrel = 115,539,382 MMBtu

Gas production in Montana in 1990:
51,537.175 Mcf x 1000 MMBtu/Mcf = 51,537,175 MMBtu

Oil and gas venting and flaring in Montana, based on total production of oil and gas in 1990:
115,539,382 MMBtu + 51,537,175 MMBtu = 167,076,557 MMBtu

Crude Oil Transportation and Refining
Oil tankered, refined and stored in Montana:
47,517,800 barrels x 5.825 MMBtu/barrel = 276,791,185 MMBtu

Natural Gas Processing, Transport and Distribution
Natural gas processing, transportation and distribution, based on gas consumed in Montana:
50,429 Mcf x 1000 MMBtu/Mcf = 50,429,000 MMBtu

Table 2.9. Methane Emissions from Natural Gas and Oil Systems.

NATURAL GAS AND OIL SYSTEM SECTOR	Production Data (MMBtu)	Emissions Factor lbs CH_4/MMBtu			Emissions Tons CH_4		
		High	Median	Low	(High/2000) High	(Median/2000) Median	(Low/2000) Low
OIL & GAS PRODUCTION					**8,445**	**5,916**	**3,388**
Oil Produced	115,539,382	0.0117	0.0062	0.00070	676	358	40
Gas Produced	51,537,175	0.1958	0.1515	0.10720	5,045	3,904	2,762
Oil & Gas Venting and Flaring	167,076,557	0.0326	0.0198	0.00700	2,723	1,654	585
CRUDE OIL TRANSPORTATION & REFINING					**775**	**512**	**270**
Oil Tankered	276,791,185	0.0017	0.0017	0.00170	235	235	235
Oil Refined	276,791,185	0.0033	0.0017	0.00020	457	235	28
Storage Tanks (Oil Refined)	276,791,185	0.0006	0.0003	0.00005	83	42	7
NATURAL GAS PROCESSING, TRANSPORT & DISTRIBUTION					6,937	**5,144**	**3,351**
Gas Consumed	50,429,000	0.2751	0.2040	0.13290	6,937	5,144	3,351
TOTAL METHANE EMISSIONS FROM NATURAL GAS AND OIL SYSTEMS (Tons CH_4)					**16,157**	**11,572**	**7,008**

Next, energy data in million Btu (MMBtu) were used to calculate methane emissions from oil production, gas production, total oil and gas production, oil tankered, oil refined and gas consumption activities. These values were multiplied by low, median and high emission factors to arrive at total methane emitted for each oil and gas activity, Table 2.9. The emissions factors were developed from studies of United States oil and gas systems as part of the IPCC emissions inventory guidelines (IPCC, 1994). The individual methane values calculated for each activity were summed to arrive at total methane emissions. The median methane emission estimate were reported as results.

Both gas found in association with oil and gas found by itself were used in calculating gas production and gas consumption in the Greenhouse Gas Inventory. The difference between these depends on the ratio of oil to gas in a producing field. For 1990 about 20 percent of the total gas produced in Montana was associated gas. Associated gas has a higher concentration of propane, butane and ethane and lower concentration of methane than non-associated gas. The heating value of natural gas is related inversely to the atmospheric pressure at the burner tip, thus the higher the altitude, the less heating value per cubic foot. Natural gas in Montana has an average of about 1000 Btu in 1 cubic foot at standard conditions.

C. Data Sources

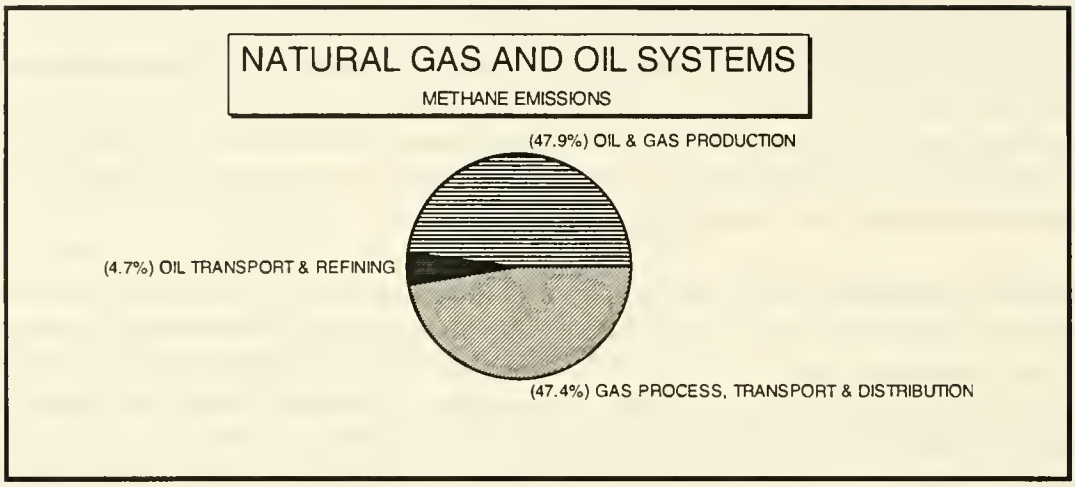
Data on oil and gas production and crude oil transportation and refining data came from the Montana Oil and Gas Annual Review 1990 (MDNRC Board of Oil and Gas Conservation, 1991). Natural gas processing, transport and distribution values as represented in the "gas consumed" column in the computer spreadsheet were taken from the Montana Energy Data report (MEQC and MDNRC, 1993) as "marketed production." Marketed production represents gross withdrawals of natural gas from gas and oil wells minus gas used for repressuring, nonhydrocarbon gas removed, and quantities vented and flared. In Montana's case this amounts to about 2 percent of the total gas produced that is lost to repressuring, venting and flaring.

D. Emissions Results

Emission estimates vary widely because emission factors depend on site specific characteristics including facility design, operation and maintenance. The State Workbook claims that emission factors are order of magnitude estimates. Estimates of total methane emissions from natural gas and oil systems in Montana in 1990 ranged from 7,008 to 16,157 tons of methane. The median emission estimate was 11,572 tons. (Table 2.9.) Approximately 48 percent of the methane emissions were from oil and gas production. Because oil and gas are often withdrawn from the same well, separating the emissions contribution from each during the processing phase is difficult. For reporting purposes emissions from oil and gas production were assumed to be equally distributed between oil and natural gas. About 5 percent of total emissions were from crude oil transportation and refining, and about 47 percent from natural gas processing, transport and distribution. (Figure 2.16.). This results in a total contribution of 3,470 tons of methane (30 percent) from oil activities and 8,102 tons of methane (70 percent) from natural gas activities.

The global warming potential of methane is 24.5 times that of carbon dioxide, meaning that a molecule of methane can have 24.5 times more effect on climate than one molecule of carbon dioxide. Therefore, greenhouse gas emissions from natural gas and oil systems are equivalent to about 283,514 tons of carbon dioxide.

Figure 2.16. Methane Emissions from Natural Gas and Oil Systems.


NATURAL GAS AND OIL SYSTEMS
METHANE EMISSIONS
(47.9%) OIL & GAS PRODUCTION
(4.7%) OIL TRANSPORT & REFINING
(47.4%) GAS PROCESS, TRANSPORT & DISTRIBUTION

IV. Coal Mining

A. Background

Methane and coal are formed together during coalification, a process in which physical and geological forces convert vegetation into coal. Methane is released when pressure within a coal bed is reduced, either through mining or through natural erosion or faulting.

Methane emissions from coal mining are related to the tons of coal mined and an emission factor related to the geologic characteristics of the coal and method of mining. More than 99 percent of Montana coal mined in 1990 was subbitumious, having a moderate heating value and moderate carbon content compared to other types of coal. In 1990, all Montana coal was surface mined. Methane emissions from surface mines are highly uncertain. However, based on available information, EPA (1995) reports that methane emissions from surface mines appear to be lower than from underground mines because the coals are typically lower ranked (less Btu's) and are buried at shallower depths.

Of the 37.6 million tons of coal mined in Montana in 1990, about 27.9 million tons were exported, about 4.7 million tons were burned in Montana and the electricity generated was exported, and about 5 million tons were burned for electricity and energy use in Montana. Methane emissions from coal used to satisfy Montana's energy needs are reported separately from emissions generated for coal and electricity exported.

B. Methodology

Coal mined in Montana was separated into three categories for the purpose of estimating methane emissions; coal mined and burned for use in Montana, coal mined and burned in Montana for electricity export, and raw coal exported.

Methane emissions from surface coal mining in Montana were calculated based on a low and high range of emission factors for the Rockies and Southwest Basin region of the United States. These emissions factors were provided in the State Workbook (EPA, 1995).

Some methane remains in the coal after it has been mined and can be emitted during the transportation and handling. These post-mining emissions were estimated by assuming that from 25 to 40 percent of the in-situ methane content of the coal escapes during post-mining activities. Emission ranges were averaged and emissions from mining and post-mining activities were summed to determine total methane emissions from coal mining in Montana.

C. Data Sources

Total coal production data for Montana 1990 were taken from the Montana Energy Data report (MEQC and MDNRC, 1993). Of the total coal produced 230,000 tons were lignite, 120,000 tons were bituminous and the remaining 37,266,000 tons (more than 99 percent of Montana coal mined) were subbituminous. Emission factors were provided in the State Workbook (EPA, 1995). The amount of Montana coal exported was determined by subtracting production values from the sum of sector consumption values (DOE/EIA, 1991B).

The amount of coal mined and burned in Montana for electricity used in-state and electricity exported out of state was estimated by comparing in-state sales to total in-state generation. (MEQC and MDNRC, 1993). Line losses were estimated to be 10 percent (DOE/EIA, 1991C).

D. Emissions Results

Estimates of total methane emissions from all coal mining and post-mining activities in Montana ranged from about 3,000 to 8,800 tons of methane. The average estimated emissions totaled 5,867 tons of methane.

Table 2.10. Methane Emissions from Coal Mining.

SURFACE MINING ACTIVITY	Coal Production thousand tons	Emission Coefficients Low Est. cf/ton	Emission Coefficients High Est. cf/ton	**Methane Emission Low Est. thousand cf**	**Methane Emission High Est. thousand cf**
Mined & burned for use in MT					
Surface mining	4,977	3	10	**14,931**	**49,770**
Post mining	4,977	0.8	1.3	**3,982**	**6,470**
Mined & burned in MT for export					
Surface mining	4,700	3	10	**14,100**	**47,000**
Post mining	4,700	0.8	1.3	**3,760**	**6,110**
Mined in MT & exported raw					
Surface mining	27,940	3	10	**83,820**	**279,400**
Post mining	27,940	0.8	1.3	**22,352**	**36,322**
TOTAL	37,617			**142,945**	**425,072**

Average CH_4 emission from instate energy use = 37,576,500 cf CH_4
20.66 tons CH_4 / 1 million cf CH_4 x 37.5765 million cf CH_4 = 776 tons CH_4 emitted from coal used in-state.

Average CH_4 emission for energy export = 246,432,000 cf CH_4
20.66 tons CH_4 / 1 million cf CH_4 x 246.432 million cf CH_4 = 5,091 tons CH_4 emitted from coal exported.

Approximately 86 percent of the emissions were from surface mining activity and approximately 14 percent from post-mining activity. Emissions were calculated for in-state energy use and for energy export. Approximately 776 tons of methane were emitted from coal mining activities for energy use in Montana, and about 5,091 tons for energy use out of state. Table 2.10.

The global warming potential of one molecule of methane is 24.5 times that of a molecule of carbon dioxide. Greenhouse gas emissions from all coal mining is equivalent to about 143,742 tons of carbon dioxide. Emissions from coal mining for in-state energy use is about 19,012 tons of carbon dioxide equivalent. Emissions from coal mining from out of state energy use total about 124,730 tons of carbon dioxide equivalent.

V. Interstate Energy Transfers

A. Background

The amount of greenhouse gas emissions from the interstate flux of fuels and electricity derived from those fuels needs to be determined to ensure that all emissions are counted for but not double counted when state totals are summed to estimate national totals.

For various reasons, such as developing mitigation and impact assessments, it is necessary to attribute emissions from electricity consumption to end-use consumers rather than to the generating state. National data sources report emissions from electricity consumption as occurring in the generating state, and the emissions are included in the source state's consumption figures. This practice grossly overstates Montana emission totals since about 60 percent of the electricity generated with Montana coal is transmitted out of state. We have solved this accounting issue by clearly identifying emissions sources and consumptions in Tables 2.11 and 2.12.

Montana is a net exporter of energy shipping almost 28 million tons of raw coal, about 3 billion cubic feet of natural gas, and about 1.4 million gallons of ethanol out of state in 1990. Net energy imports in 1990 included about 28 million barrels of crude oil, and 40 thousand barrels of No. 2 fuel oil. Montana also exported about 85 billion Btu of coal in the form of electricity.

B. Methodology

Carbon dioxide emissions for interstate energy transfers were computed using the methods described in the State Workbook (EPA, 1995) and following the same methods used in calculating emissions from fossil and biomass based fuels. Table 2.11 details the calculation for carbon dioxide emissions for imported and exported fuels and for electricity generation.

C. Data Sources

Distillate fuel oil import data are from the report, Cost and Quality of Fuels for Electric Utility Plants (DOE/EIA, 1991A). Ethanol import and export data and coal production data are from the Montana Energy Data report (MEQC and MDNRC, 1993). Total coal production data for Montana 1990 were taken from the Montana Energy Data report (MEQC and MDNRC, 1993).

The amount of Montana coal exported was determined by subtracting production values from the sum of sector consumption values (DOE/EIA, 1991B). The amount of coal mined and burned in Montana for electricity used in-state and electricity exported out of state was estimated by comparing in-state sales to total in-state generation (MEQC and MDNRC, 1993). Line losses were estimated to be 10 percent (DOE/EIA, 1991C). Crude oil and natural gas export and import figures are from MDNRC, Board of Oil and Gas Conservation (1991).

D. Emissions Results

About 23 million tons of carbon dioxide were emitted through the combustion of imported fossil and biomass fuels in Montana. Carbon dioxide emissions from the combustion of exported fuels total almost 63 million tons. Carbon dioxide emissions from exported electricity totaled about 9 million tons (Table 2.11). Net exported carbon dioxide emissions from interstate energy and electricity transfers equals about 49 million tons for 1990 (Table 2.12). For comparison purposes, net exported emissions are more than double the carbon dioxide equivalent emissions from the energy sector in Montana.

Table 2.11. Montana Interstate Energy and Electricity Transfer in 1990.

Source/Fuel	Conversion	Input Energy Imported/Exported (MBtu)	Assumption C Content Coefficient (lbs C/MBtu)	Calculated Net Carbon (tons C)	Calculated Total Carbon Oxidized (tons C)	Calculated Carbon Dioxide Emissions (tons CO_2)
Imported						
43,702,684 barrels crude oil	5.80 MBtu/barrel	253,475,567	44.7	5,665,179	5,608,527	20,564,600
37,963,996 mcf natural gas	1.03 MBtu/mcf	39,102,916	31.9	623,692	617,455	2,264,000
430,421 gallons ethanol	0.0764 MBtu/gal	32,884	41.8	687	680	2,495
40,000 barrels No.2 fuel oil	5.825 MBtu/barrel	233,000	44.0	5,126	5,075	18,607
Total Imported		**292,844,367**				**22,849,702**
Exported						
15,700,000 barrels crude oil	5.80 MBtu/barrel	91,060,000	44.7	2,035,191	2,014,839	7,387,743
41,003,179 mcf natural gas	1.03 MBtu/mcf	42,233,274	31.9	673,621	666,885	2,445,243
1,826,340 gallons ethanol	0.0764 MBtu/gal	139,532	41.8	2,916	2,887	10,586
27,940,000 tons coal	18.024 MBtu/tons	503,590,560	57.9	14,578,947	14,433,157	52,921,577
27,940,000 tons coal mined	(see methane emissions from coal mining section)					106,771
Total Exported		**637,023,367**				**62,871,920**
Electricity Exported						
4,700,000 tons coal (electricity)	18.024 MBtu/gal	84,712,800	57.9	2,452,436	2,427,911	8,902,341
4,700,000 tons coal mined	(see methane emissions from coal mining section)					17,959
Total Exported						**8,920,300**

Table 2.12. Net Exported Carbon Dioxide Emissions from Interstate Energy and Electricity Transfers.

Net Interstate CO_2 Emissions Transfer

Total Fuel Exported	-	Total Fuel Imported	=	Net Interstate CO_2 Emissions Transfer from Raw Fuel
62,871,920 tons CO_2	-	22,849,702 tons CO_2	=	**40,022,218 tons CO_2 Exported from Raw Fuel**
Total Coal Generated Electricity Exported			=	**8,920,300 tons CO_2 Exported from Electricity**

VI. References

DOE/EIA--see U.S. Department of Energy, Energy Information Agency.

EPA--see U.S. Environmental Protection Agency.

IPCC--see Intergovernmental Panel on Climate Change.

MEQC--see Montana Environmental Quality Council.

MDNRC--see Montana Department of Natural Resources and Conservation.

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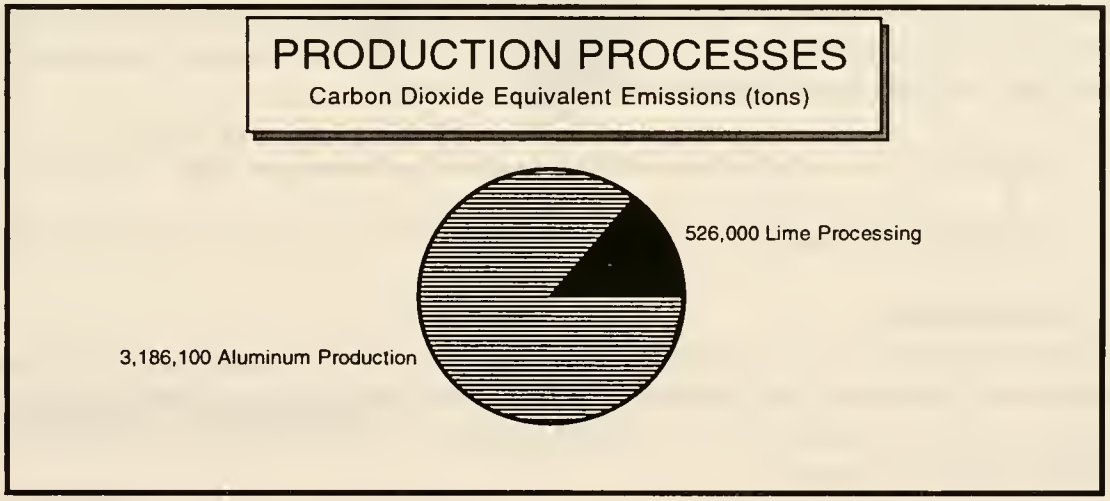
Chapter 3. Production Processes Related Emissions

I. Summary

Non-energy related greenhouse gases are emitted as by-products of some industrial and commercial manufacturing processes. For example, in the industrial sector raw materials are chemically transformed from one state to another. This transformation often results in the release of greenhouse gases such as carbon dioxide and halogenated fluorocarbons. The production processes addressed in the Montana greenhouse gas emissions inventory include lime processing and aluminum production. Both processes emit carbon dioxide. Aluminum production also releases various fluoride compounds including carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6). Total Montana greenhouse gas emissions from lime processing and aluminum production for 1990 are equivalent to about 3,712,100 tons of carbon dioxide ($CO_{2)}$. Lime processing contributed about 526,000 tons (about 14 percent of carbon dioxide) while aluminum production contributed the remaining 86 percent (3,186,100 tons) of carbon dioxide equivalent. Figure 3.1.

Figure 3.1. Carbon Dioxide Equivalent Emissions from Production Processes.



Other production processes release greenhouse gases into the atmosphere, but these emissions are either quite small or can not be measured with current methods.

II. Lime Processing

A. Background

For inventory purposes lime processing includes cement and lime manufacturing, and use of lime in paper pulp kilns. Montana has two cement production facilities, one lime manufacturing facility and one pulp paper mill.

B. Methodology

Greenhouse gas emissions for lime processing were computed based on methods provided in the State Workbook (EPA, 1995) and modified by methods used in the Washington State Greenhouse Gas Inventory. For cement, lime, and paper pulp kilns, carbon dioxide emissions are estimated by multiplying tons of material production by an emissions factor of carbon dioxide per ton of material produced.

1. Cement Manufacturing

The primary release of carbon dioxide during cement production occurs in the manufacture of clinker, an intermediate product from which cement is made. One component of clinker is lime (calcium oxide, CaO). Emissions from limestone processing occur when limestone (calcium carbonate, $CaCO_3$) is heated to form lime (CaO) and carbon dioxide (CO_2) is released to the atmosphere.

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2$$

The State Workbook recommends using an emission coefficient of 0.507 tons of carbon dioxide per ton of clinker produced. This emissions factor assumes an average composition for clinker of 64.6 percent lime.

Total CO_2 emissions (tons) = 589,892 tons of cement produced in Montana in 1990 x 0.507 ton CO_2/ ton clinker.

= 299,075 tons CO_2 emitted.

2. Lime Manufacturing

Major uses of lime include steel making, construction, pulp and paper manufacturing and water and sewage treatment. Lime is manufactured by heating limestone in a kiln, creating calcium oxide and carbon dioxide. This leads to emission of carbon dioxide into the atmosphere. The State Workbook recommends using an emissions factor of 0.785 tons of carbon dioxide per ton of lime.

Total CO_2 emissions (tons) = 152,094 tons of lime produced in Montana in 1990 x 0.785 ton CO_2/ ton lime.

= 119,394 tons CO_2 emitted.

3. Paper Pulp Kilns

The factor for paper pulp lime kiln emissions is based on tons of air-dried paper pulp (ADPP) produced. According to the Washington State Greenhouse Gas Inventory (Washington State Energy Office, 1993), a ton of lime is required to neutralize 4 tons of ADPP produced in the pulping process. The emission factor for pulping facilities in Montana is:

Emission Factor = 0.25 tons CO_2/ ton ADPP x 0.785 tons CO_2/tons lime.

= 0.1963 ton CO_2 / ton air-dried paper pulp produced

Total CO_2 emissions (tons) = 547,629 tons of ADPP produced in Montana in 1990 x 0.1963 ton CO_2/ ton ADPP.

= 107,500 tons CO_2 emitted.

Total CO_2 emissions (tons) from lime processing.

299,075 tons (cement production) + 119,394 tons (lime production) + 107,500 tons (paper pulp)

= 525,969 tons CO_2 emitted.

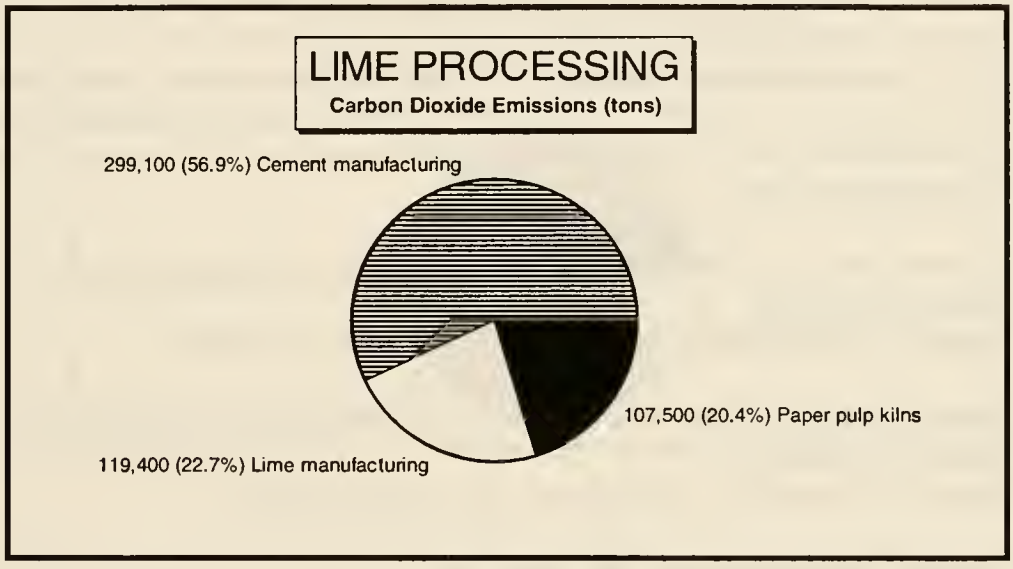
C. Data Sources

Cement, paper pulp and lime production data for 1990 in Montana were provided by industry representatives, Chorney (1996), Howard (1996), Phillips (1996) and Savage (1996). Limestone production was reported to the State Department of Revenue and published in the Biennial Report of the Montana Department of Revenue for the period July 1, 1990 to June 30, 1992.

D. Emissions Results

Of the 526,000 tons of carbon dioxide emissions from lime processing, 299,100 tons were from cement manufacturing, 119,400 tons from lime manufacturing, and 107,500 tons from paper pulp manufacturing. Figure 3.2.

Figure 3.2. Carbon Dioxide Emissions from Lime Processing.



III. Aluminum Production

A. Background

Aluminum production releases carbon dioxide and fluoride compounds including carbon tetrafluoride and carbon hexafluoride. These halogenated fluorocarbons are potent greenhouse gases with global warming potentials of about 8,400 (Abrahamson, 1992A). This section estimates greenhouse gas emissions from the production process of manufacturing aluminum and does not include the energy used in the manufacturing process. Emissions from energy used in industrial processes is discussed in Chapter 2. There is one aluminum production facility in Montana.

B. Methodology

Estimated greenhouse gas emissions for aluminum production were based on methods provided in the State Workbook (EPA, 1995) with emission factors modified by Abrahamson (1992A,B).

Aluminum production involves the reduction of aluminum oxide (Al_2O_3) with carbon using an electrolytic process, forming aluminum and carbon dioxide. The State Workbook (EPA, 1995) does not discuss carbon dioxide emissions from aluminum production. However, research reported by Abrahamson (1992A) indicates that 1.5 to 2.2 tons of carbon dioxide are emitted per ton of aluminum produced. The emission factor used for this inventory is the average of the low and high range from these two data sources, 1.9 tons carbon dioxide per ton aluminum produced.

Total CO_2 emissions (tons) = 187,000 tons aluminum produced x 1.9 ton CO_2/ ton Al produced.
= 355,300 tons CO_2 emitted.

Chlorofluorocarbon emissions provided by the State Workbook (EPA, 1995) are estimated to range from 0.0003 to 0.0009 ton carbon tetrafluoride per ton aluminum produced and a magnitude less for carbon hexafluoride. However, Abrahamson (1992B) reports that a more accurate estimate of emission factors from aluminum smelting is 0.0014 to 0.0018 ton carbon tetrafluoride per ton Al produced, and 0.00018 to 0.00022 ton carbon hexafluoride per ton Al produced. This estimate is based upon the rate of increase of atmospheric concentrations of carbon tetrafluoride and carbon hexafluoride and global aluminum production data. The Montana inventory of greenhouse gas emissions uses Abrahamson estimates for aluminum production.

Total CF_4 emissions (tons) = 187,000 tons Al produced x 0.0016 ton CF_4/ ton Al produced.
= 300 tons CF_4 emitted.
300 tons CF_4 x 8400 GWP = 2.52 million tons CO_2 equivalent emitted.

Total C_2F_6 emissions (tons) = 187,000 tons Al produced x 0.0002 ton C_2F_6/ ton Al produced.
= 37 tons C_2F_6 emitted.
37 tons C_2F_6 x 8400 GWP = 310,800 tons CO_2 equivalent emitted.

Total CO_2 equivalent emitted from aluminum production:
355,300 tons + 2,520,000 tons + 310,800 tons = 3,186,100 tons CO_2 equivalent.

Assuming there are about 30 aluminum cans per pound, more than one half a pound of carbon dioxide equivalent greenhouse emissions are released into the atmosphere for every aluminum can produced.

$$\frac{3{,}186{,}100 \text{ tons } CO_2 \text{ equivalent}}{187{,}000 \text{ tons Al produced}} \times \frac{1 \text{ lb. Al}}{30 \text{ cans}} = \frac{0.57 \text{ lbs } CO_2}{\text{can}}$$

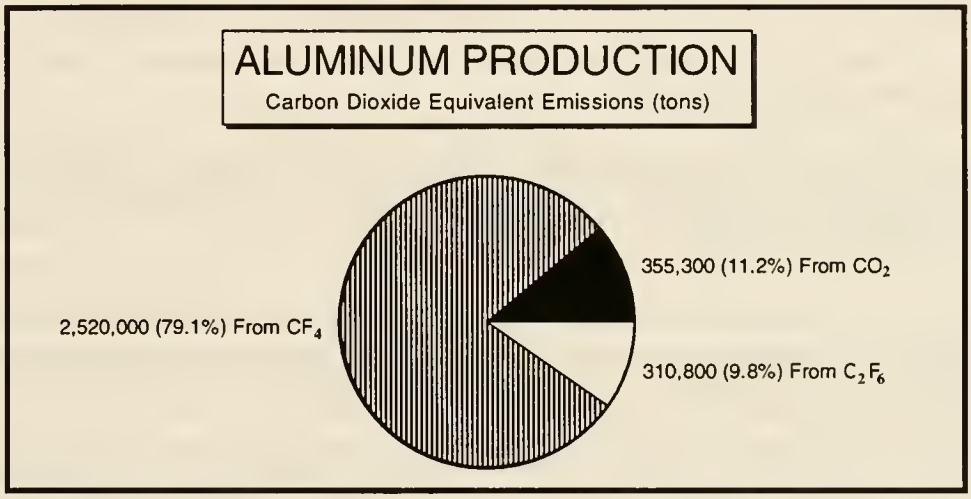
C. Data Sources

Aluminum production data for 1990 in Montana was provided by Ryan (1996). Emissions factors for aluminum production were reported by Abrahamson (1992).

D. Emissions Results

Aluminum manufacturing emits carbon dioxide, carbon tetrafluoride, and carbon hexafluoride. Approximately 355,300 tons of carbon dioxide were emitted, 300 tons of carbon tetrafluoride, and 37 tons of carbon hexafluoride. Carbon tetrafluoride and carbon hexafluoride have estimated global warming potentials of about 8,400, therefore, the carbon dioxide equivalent emissions from halogenated fluorocarbons from aluminum production processes are 2,830,800 tons, (Figure 3.3). Total emissions from aluminum manufacturing in Montana are about 3,186,100 tons of carbon dioxide equivalent.

Figure 3.3. Carbon Dioxide Equivalent Emissions from Aluminum Manufacturing.



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Chapter 4. Agriculture Related Emissions

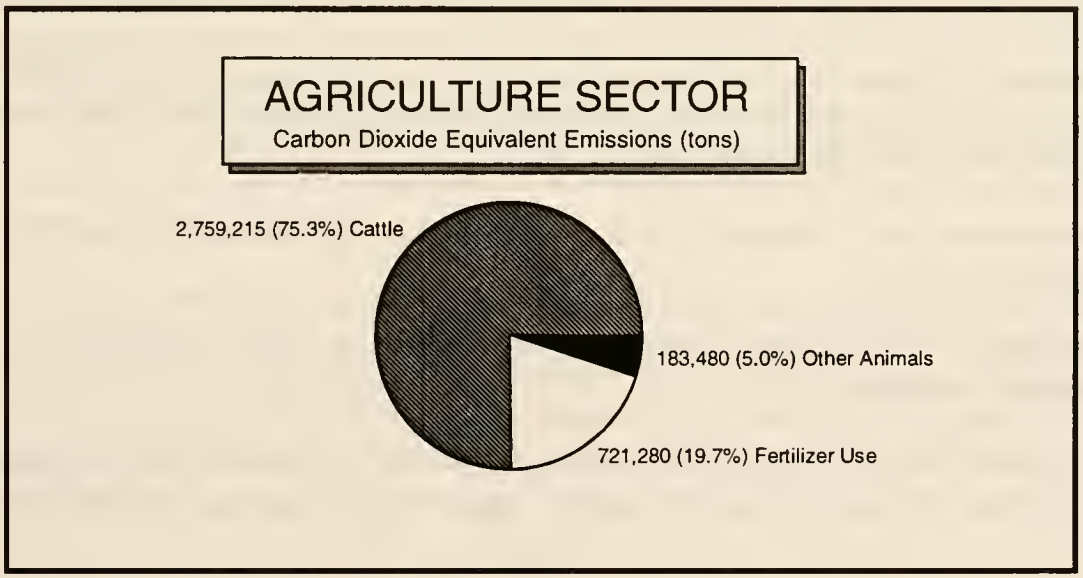
I. Summary

Agriculture related greenhouse gas emissions result from domestic animals, fertilizer applications, manure management systems, and crop residue burning. However, in Montana 97 percent of manure decomposes naturally on pasture and range releasing little or no methane. Likewise, open crop residue burning is not common practice in Montana, and greenhouse gas emissions from this category are negligible.

Domesticated animals release methane (CH_4) as a natural by-produce of digestion. Approximately 120,000 tons of methane were released from domestic animal digestion in Montana in 1990, and about 94 percent of this was from cattle. This equates to about 2,940,000 tons of carbon dioxide equivalent. Before human involvement, methane was produced by non-domesticated animals, mainly buffalo. Since domesticated cattle have largely replaced the buffalo, net methane emissions from this source are considerably less than in the past.

Nitrogen based fertilizer use in Montana emitted approximately 2,250 tons of nitrous oxide (N_2O) to the atmosphere in 1990. This is equivalent to about 720,000 tons of carbon dioxide (CO_2). Carbon dioxide equivalent emissions from the agriculture sector in Montana are summarized in Figure 4.1.

Figure 4.1. Methane Emissions from Domestic Animals.



II. Domesticated Animals

A. Background

Methane (CH_4) is a produced naturally by animal digestion through a process called enteric fermentation. Microbes in the animal's digestive system break down feed and methane is produced by methanogenic bacteria as a by-product of fermentation. The methane is then released into the air by the animals burping and exhaling. Two components that play a major part in determining the amount of emissions are the animal's digestive system and the amount and type of feed. Ruminant animals are those which have a rumen, or a large "forestomach." This type of animal includes cattle, buffalo, sheep, and goats, and produces the highest methane emissions because of physiological makeup. Pigs and horses are non-ruminant and produce less methane. Overall, because of their population and size, cattle account for most methane emissions from domestic animals.

B. Methodology

While it is possible to measure methane emissions from individual animals, it obviously is not practical to measure emissions from large numbers of animals. Instead, methane emissions are estimated by multiplying data on animal populations by emissions factors for each animal type and summed to arrive at total annual methane emissions.

Models have been developed to estimate emission factors for individual animal types. For cattle, EPA used a detailed methodology to estimate emissions. The U.S. was divided into five geographic regions based on representative cattle types, diets, and management practices. Nine different cattle types were evaluated in each of the five regions and emission factors were estimated for each type using a mechanistic model of rumen digestion.

Two modifications were made to the State Workbook (EPA, 1995) method. Livestock statistics for Montana report beef cows and weanling and yearling steers and heifers together, so dividing this data as the State Workbook described was not possible. An average of the emissions factors provided for beef cows and yearlings was used (128.4 lbs/head/year) to estimate methane emissions. Also, replacement cattle statistics for Montana are not divided between 0-12 months and 12-24 months as described in the State Workbook, but reported as one number. For the emissions inventory, we averaged the emission factor of these two age groups for an emissions factor of 96.3 pounds of methane per head per year for beef cattle and 90 pounds of methane per head per year for dairy cattle.

Methane emissions were calculated for each animal type using the following formula from the State Workbook (EPA, 1995):

Animal Population x Methane Emission Factor (for specific animal type) x 1 ton/2000 lbs
= Methane Emissions (tons)

Emission totals for each animal type were added to arrive at the total methane emissions from domestic animals. Calculations based on population statistics, emissions factors and total emissions are reported in Table 4.1.

Table 4.1. Methane Emissions from Domestic Animals.

ANIMAL TYPE	1990 Population Head	Emission Factor lbsCH_4/head/yr	Emissions Tons CH_4
Dairy Cattle			**3,465**
Replacements (0-24 mos.)	7,000	90.0	315
Mature Cows	24,000	262.5	3,150
Beef Cattle			**109,156**
Replacements (0-24 mos.)	325,000	96.3	15,649
Mature Cows/Weanling/Yearling	1,328,000	128.4	85,258
Bulls	75,000	220.0	8,250
Sheep	663,000	17.6	**5,834**
Goats	6,752	11.0	**37**
Pigs	185,000	3.3	**305**
Horses	64,386	39.6	**1,275**
Mules	1,580	48.5	**38**
Total			**120,110**

C. Data Sources

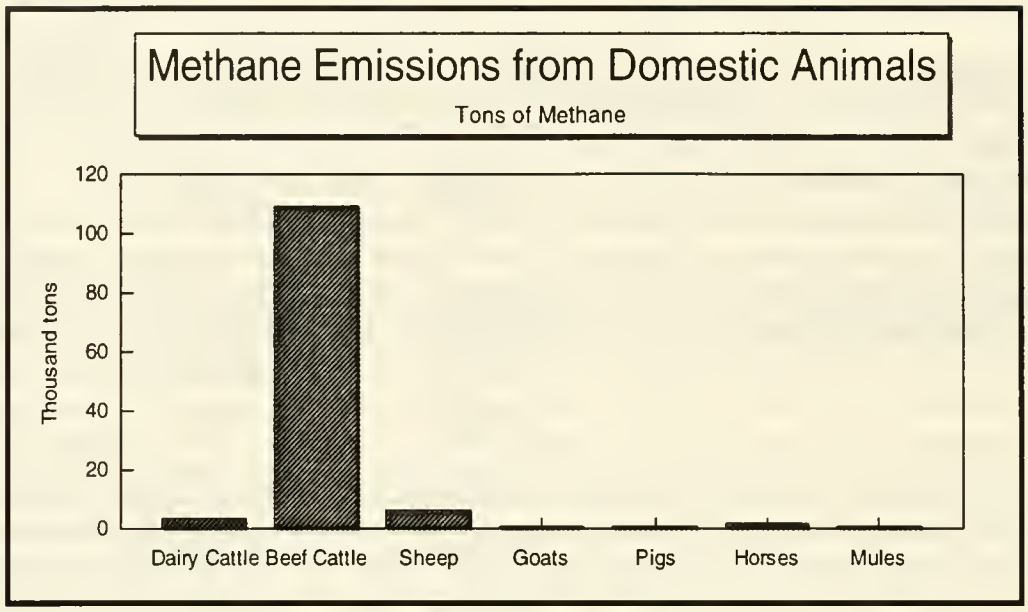
Domestic animal population data were gathered from reports published by the Montana Department of Agriculture (1992) Montana Agriculture Statistics, the U.S. Department of Agriculture (1992) Agricultural Statistics, and the U.S. Department of Commerce (1987, 1992) Census of Agriculture. Data reported in the 1987 and 1992 Census of Agriculture were averaged to get population estimates for the year 1990.

D. Emissions Results

The total annual emissions from domestic animals in Montana is estimated to be 120,110 tons of methane. Cattle are the major contributors of all domestic animals with an estimated methane emission of 109,156 tons from beef cattle, and 3,465 tons from dairy cattle. Emissions from sheep, goats, pigs, horses, and mules total about 7,489 tons. Figure 4.2.

The global warming potential for methane is 24.5 times that of carbon dioxide, meaning that a volume of methane has 24.5 times the effect on climate of an equal volume of carbon dioxide. Greenhouse gas emissions from domestic animals are equivalent to 2,942,695 tons of carbon dioxide. Beef cattle produce about 2.7 million tons of carbon dioxide equivalent emissions (91 percent), dairy cattle about 84,892 tons (3 percent), sheep about 142,933 tons (5 percent) and goats, pigs, horses, and mules combined less than 40,548 tons (1 percent).

Figure 4.2. Methane Emissions from Domestic Animals.



III. Fertilizer Application

A. Background

Nitrous oxide (N_2O) is produced naturally in soils through the microbial processes of denitrification (anaerobic) and nitrification (aerobic). The use of nitrogen-based synthetic and organic fertilizers for improved crop production adds nitrogen to the soils which increases atmospheric emissions of nitrous oxide above natural background levels.

Components that affect nitrous oxide emissions from fertilizers include management practices such as irrigation methods, tillage techniques and fallowing of land, fertilizer type, nitrogen content, application rate and frequency, crop system, soil type, moisture, carbon content, and temperature. Due to the large number of components and limited scientific knowledge regarding nitrous oxide production and emissions from fertilized soils, emission estimates are given as a range.

B. Methodology

Nitrous oxide emissions from fertilizer use are estimated in accordance with the methods presented in the State Workbook. This method uses a general nitrous oxide emission coefficient per unit mass of nitrogen for each fertilizer type. State fertilizer data are published annually in the Montana Commercial Fertilizer Report. In accordance with the State Workbook methodology, 3-year average fertilizer consumption (based on sales) for each fertilizer type has been computed. The purpose of the 3-year average is to eliminate variations in fertilizer use due to weather or economic conditions. The emission factor suggested in the State Workbook of 0.0117 tons was used for this inventory. Emissions are reported in total nitrous oxide in tons by using the molecular weight conversion factor of 44/28. Table 4.2.

Table 4.2. Nitrous Oxide Emissions from Fertilizer Applications.

FERTLIZER TYPE	FERTILIZER USE(TONS)			(A) Average Tons	(B) Average %N	(AXB)=C Nitrogen Tons	(D) Emissions Factor $\%N_2O$-N	(CxD)=F N_2O-N Tons	(Fx44/28) Emissions N_2O tons
	1989	1990	1991						
Ammonia, anhydrous	42,277	44,942	46,806	44,675	82%	36,634	1.17%	429	674
Ammonium nitrate	63,873	47,911	50,944	54,243	34%	18,443	1.17%	216	339
Ammonium nitrate-limestone mix	226	293	208	242	21%	51	1.17%	1	1
Ammonium sulfate	11,077	9,077	11,755	10,636	21%	2,234	1.17%	26	41
Ammonium sulfate-nitrate	2,299	944	453	1,232	26%	320	1.17%	4	6
Nitrogen solutions	14,112	12,573	9,478	12,054	30%	3,616	1.17%	42	66
Urea	72,253	81,978	62,996	72,409	46%	33,308	1.17%	390	612
Ammoniated superphosphate	8,192	5,309	3,656	5,719	45%	2,574	1.17%	30	47
Ammonium phoshpate-nitrate	3,393	2,156	3,038	2,862	27%	773	1.17%	9	14
Ammonium phosphate-sulfate	14,216	15,285	8,224	12,575	13%	1,635	1.17%	19	30
Diammonium phosphate	45,914	39,735	36,387	40,679	19%	7,729	1.17%	90	142
Monoammonium phosphate	76,372	84,234	80,508	80,371	11%	8,841	1.17%	103	163
Nitric phosphates	2,271	2,360	8,457	4,363	18%	785	1.17%	9	14
Nitrate of soda potash	33,974	34,750	40,274	36,333	15%	5,450	1.17%	64	100
Potassium nitrate	354	806	3,112	1,424	13%	185	1.17%	2	3
TOTAL				**379,817**		**122,577**			**2,254**

N_2O emissions from fertilizer use were estimated as follows:

1. Compile 3-year average (1989, 1990, 1991) annual sales data for each type of fertilizer used (tons).

2. Multiply 3-year average fertilizer consumption by nitrogen content of each fertilizer type = fertilizer (tons of N).

3. Multiply fertilizer (tons of N) by emission coefficient of 0.0117 tons N per ton of N-applied, for each type of fertilizer (assumes that 1.17 percent of the nitrogen applied as fertilizer is released in the atmosphere as nitrous oxide).
   = N_2O-N emissions (tons of N_2O-N).

4. Multiply N_2O-N emissions by 44/28 (molecular weight ratio)
   = N_2O emissions (tons of N_2O).

5. Sum across all fertilizer types to obtain total N_2O emissions.

C. Data Sources

Consumption data for fertilizer in Montana was found in the 1989, 1990 and 1991 Montana Commercial Fertilizer Reports, obtained from the Montana Department of Agriculture. Steve Reymann (1995) Agricultural Specialist with the Montana Department of Agriculture reviewed assumptions, methodology and results for fertilizer use.

Nitrogen conversion factors used were from the State Workbook (EPA, 1995) method, except for nitrogen solution in which state data were used. The Montana Commercial Fertilizer Reports provide a range of 28 to 32 percent nitrogen in the nitrogen solution fertilizers. Average nitrogen content for each fertilizer was used in this inventory.

D. Emissions Results

Estimated nitrous oxide emissions from fertilizer use for 1990 in Montana was 2,254 tons. The global warming potential of nitrous oxide is 320. Greenhouse gas emissions from fertilizer use in Montana thus is equivalent to about 721,280 tons of carbon dioxide.

Fertilizer use is the most significant source of nitrous oxide in the United States. Nitrous oxide emissions in 1990 due to consumption of synthetic and organic fertilizers total about 13.5 million metric tons of carbon dioxide equivalent. This represents approximately 45 percent of total U.S. nitrous oxide emissions and about 97 percent of nitrous oxide emissions from all agriculture sources. (EPA, 1995).

IV. Manure Management

When animal manure decomposes anaerobically (without exposure to oxygen), decomposition of the organic material in the manure produces methane. The components which affect the amount of methane produced

are the type and quantity of manure produced (primarily depending on the animal type) and the way in which the manure is managed. Different handling systems affect the amount of methane produced and released. Specifically, liquid systems such as lagoons, higher temperatures and moist climatic conditions promote methane production. When manure is handled as a solid or when it is deposited naturally on pastures and rangelands, it tends to decompose aerobically and produces little or no methane.

Manure in Montana is mostly (97 percent) deposited naturally on pasture and range and about 3 percent on dry feedlots. Neither system results in high methane releases. In a dry feedlot system, the animals are kept in unpaved confinement where the manure dries. At periodic intervals, the manure is hauled and often applied to fields. Due to Montana's arid climate and wide use of pasture and range, greenhouse gas emissions from manure are insignificant and not included in this inventory.

V. Burning of Crop Waste

The State Workbook (EPA, 1995) lists crop residue burning as a significant source of methane, nitrogen oxides and nitrous oxide. Although Montana is an agriculture state, open burning of crop residues is not a common practice (Reymann, 1995) and therefore the emissions from this category are negligible and not included in this inventory.

VI. References

EPA--see U.S. Environmental Protection Agency

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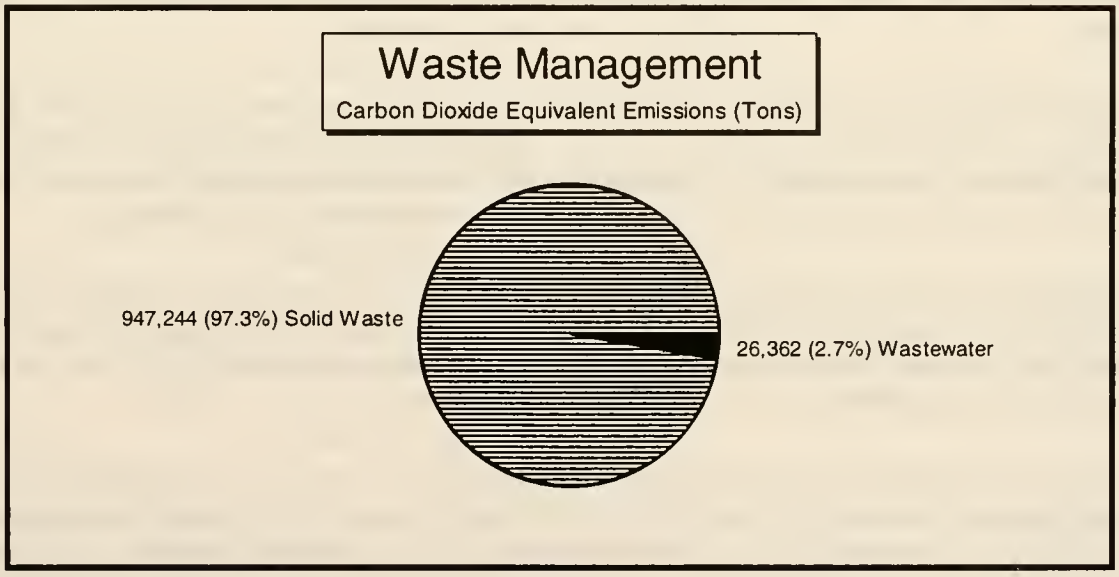
Chapter 5. Waste Management

I. Summary

The waste management chapter includes greenhouse gas emissions from wastewater treatment facilities and landfills. Both wastewater treatment facilities and landfills release methane (CH_4) during anaerobic processing of organic materials. Three of the four main wastewater treatment methods used in Montana produce methane gas. These include anaerobic mechanical treatment (serving 23 percent of the population), lagoon systems (serving 13 percent), and septic systems (serving 50 percent). The non-methane gas producing aerobic mechanical treatment systems serve about 14 percent of the population. Wastewater treatment facilities in Montana emit about 1,076 tons of methane, or about 26,362 tons of carbon dioxide equivalent.

Municipal landfills contribute about 95 percent of the methane emissions from waste disposal, while emissions from industrial landfills make up the remaining 5 percent. Total emissions from landfills equal about 38,663 thousand tons of methane, or about 947,243 thousand tons of carbon dioxide equivalent. Figure 5.1 shows methane emissions from both wastewater treatment facilities and landfills.

Figure 5.1. Carbon Dioxide Equivalent Emissions from Waste Management.



II. Municipal Wastewater

A. Background

Wastewater treatment can be either; aerobic or anaerobic. Methane (CH_4) is produced when organic material is degraded in the absence of oxygen. Three of the four main wastewater treatment methods used in Montana operate under anaerobic conditions resulting in the production of methane. These include anaerobic mechanical treatment, lagoon systems, and septic systems. The fourth method, aerobic mechanical treatment systems, do not produce methane.

Eight mechanical treatment plants in Montana rely on anaerobic digestion as part of the solids processing. In 1995, these eight facilities served approximately 210,000 people. This type of digestion produces digester gas which is about 65 percent methane. One mechanical treatment plant relied solely on aerobic digestion or heat treatment which does not generate methane. The aerobic treatment plant served nearly 125,000 people.

Wastewater lagoons also rely on anaerobic treatment processes. In Montana, these lagoons serve approximately 120,000 people. It is estimated that about 20 percent of the gas produced within these systems is methane (Burke, 1995).

The remaining 450,000 persons in Montana are served by on-site treatment systems, primarily septic systems. Septic tanks have a very slow-rate anaerobic process. About 70 percent of the biogas produced from these systems consists of methane. (Abrahamson, 1996).

B. Methodology

The amount of wastewater data in Montana allows more accurate emission estimates than provided by the basic method of the State Workbook. The method used for this inventory was briefly discussed in the State Workbook as the complex method and has been modified slightly for Montana as described below.

The population data for Montana provided in the background section above were for 1995, in which the state population was about 905,000 persons. The population for Montana in 1990 was actually 799,065 people. It was assumed that population distribution among the four main wastewater treatment types were proportional between 1990 and 1995, and the data were adjusted accordingly.

For biochemical oxygen demand (BOD_5), a value of 0.2 lb BOD_5/capita/day, as stated in the Design Standards for Wastewater Facilities (MDHES, 1995) was applied. Methane emissions for each wastewater treatment method were estimated using the methane conversion factor discussed in the background section above.

The amount of methane recovered for energy use or flared was estimated and subtracted to get the net annual methane emissions total. Information from Howard Haines (1996) revealed an estimated total of 1,164 tons of biogas were used for energy purposes or flared in Montana from five large mechanical wastewater treatment facilities in 1990. Approximately 60 percent of the gas is methane, indicating an estimated 700 tons of methane were recovered from the five mechanical facilities in 1990. Joe Steiner

(1995) and Mike Garrity (1995) from the Billings and Helena wastewater treatment facilities estimated that about 80 percent of the methane generated from anaerobic mechanical treatment facilities in Montana is used or flared while the remainder is emitted as methane gas to the atmosphere. The 80 percent estimate agrees with Haines' estimate.

The final step is to sum emissions from the individual treatment methods.

The step-by-step methodology to estimate methane emissions from wastewater treatment facilities is presented below.

1. Determine Portion of State Population Using Each Type of Wastewater Treatment System in 1990.

The U.S. Census reported 799,065 people in Montana in 1990.

Convert 1995 population and treatment data to 1990 population and treatment data.

210,000 (799,065/905,000) = 185,418 people on mechanical treatment - anaerobic.
125,000 (799,065/905,000) = 110,368 people on mechanical treatment - aerobic.
120,000 (799,065/905,000) = 105,953 people on lagoon systems.
450,000 (799,065/905,000) = 397,326 people on septic systems.

2. Estimate Methane Emissions from each Treatment Method.

a. Mechanical treatment - anaerobic
(185,418 people) x (0.2 lbs BOD_5/capita/day) x (365 days/year) x (0.22 lbs CH_4/lbs BOD_5) x (.65 methane conversion factor) x (1 ton/2000 lbs) = 968 tons CH_4 emitted
- 700 tons CH_4 recovered or flared
= 268 tons CH_4/year.

b. Mechanical treatment - aerobic
(110,368 people) x (0.2 lbs BOD_5/capita/day) x (365 days/year) x (0.22 lbs CH_4/lbs BOD_5) x (0.0 methane conversion factor)
= 0 tons CH_4/year.

c. Lagoon systems
(105,953 people) x (0.2 lbs BOD_5/capita/day) x (365 days/year) x (0.22 lbs CH_4/lbs BOD_5) x (.20 methane conversion factor) x (1 ton/2000 lbs)
= 170 tons CH_4/year.

d. Septic systems
(397,326 people) x (0.2 lbs BOD_5/capita/day) x (365 days/year) x (0.22 lbs CH_4/lbs BOD_5) x (.70 methane conversion factor) x (1 ton/2000 lbs)
= 638 tons CH_4/year.

3. **Estimate Net Annual Methane Emissions.**

Sum emissions from individual wastewater treatment methods.

(268 tons CH_4/year + 170 tons CH_4/year + 638 tons CH_4/year)
= 1,076 tons CH_4 emitted /year.

C. Data Sources

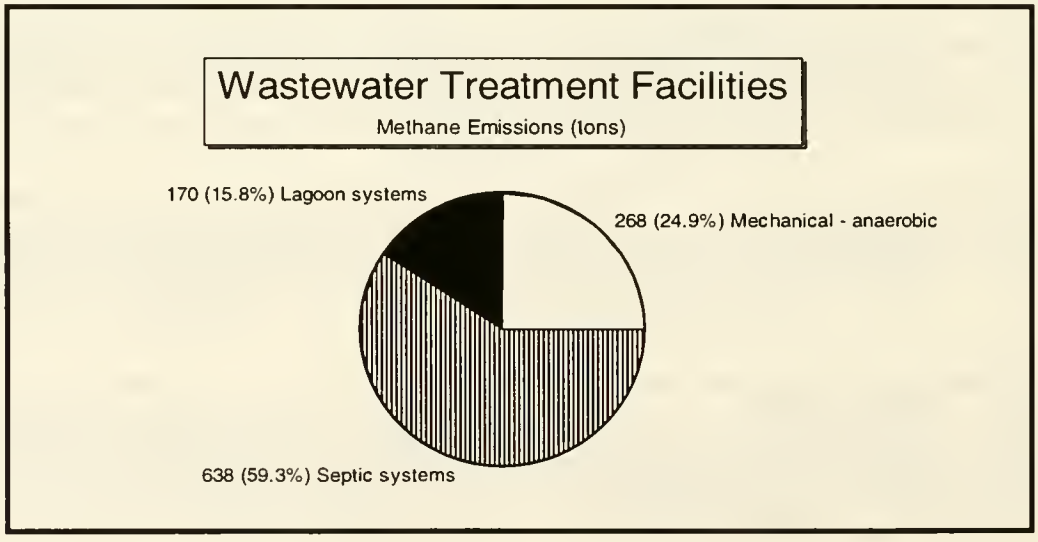
Data used for state-specific population and treatment percentages were obtained from Pat Burke (1995) of the MDEQ Water Quality Division. Figures on percent methane content of gas and estimated amount of methane used or flared were provided by Mike Garrity (1996) from the Helena Wastewater Treatment facility. Amount of methane gas used was also provided by Joe Steiner (1995) of the Billings Public Utilities Department. Howard Haines (1996) provided information on biogas consumed and flared. The default values used for lbs/capita/day and for converting to CH_4 were given in the State Workbook (EPA, 1995). Biochemical oxygen demand values were provided by MDHES (1995). Mike Abrahamson (1996) reviewed assumptions made in estimate methodology and wastewater section results.

D. Emissions Results

Total methane emissions from municipal wastewater treatment estimated for 1990 were 1,776 tons. This number includes about 700 tons used for electricity or heat as an energy source or flared. The total net emissions of methane from wastewater treatment systems in 1990 was approximately 1,076 tons including an estimated net emissions of 268 tons from mechanical anaerobic treatment, 170 tons of emissions from lagoon systems and 638 tons from septic systems. Figure 5.2.

The global warming potential for a given volume of methane is 24.5 times that of an equivalent volume of carbon dioxide. Greenhouse gas emissions from wastewater treatment facilities are equivalent to about 26,362 tons of carbon dioxide or about an average of 66 pounds of carbon dioxide per person for 1990 in Montana.

Figure 5.2. Methane Emissions from Wastewater Treatment Facilities.



III. Landfills

A. Background

Methane (CH_4) and carbon dioxide (CO_2) are produced as a result of the decomposition of organic material in landfills in an anaerobic environment. While landfill gas contains roughly equal amounts of methane and carbon dioxide, carbon dioxide emissions from landfills are relatively small compared to carbon dioxide emissions from other sources. However, methane emissions from landfills nationwide are the largest single source of human generated methane.

Waste exposed to open air decomposes under aerobic conditions producing carbon dioxide. Waste disposal in tightly packed landfills is more conducive to anaerobic decomposition. Because landfills today are capped with soil or other covering materials that exclude oxygen, they produce relatively larger amounts of methane than older landfills. Although the amount of methane produced has increased as a result of current landfilling practices, the ability to recover this methane also has greatly improved.

No landfill gas recovery or flaring programs were operating in Montana in 1990, so all landfill gas was emitted directly to the environment.

The rate at which methane is generated from landfills is determined by the organic content of the landfilled material and the environment surrounding the landfill. Variables such as particle size, waste compaction, temperature, and moisture content of the landfill all affect methane production. Conditions are likely to vary among different landfills and within a single landfill, producing methane at different rates and volumes.

In Montana in 1990, approximately 94 percent of waste was landfilled in Class II municipal solid waste landfills (MSW landfills) and about 4.3 percent was landfilled in Class III landfills (designed for inert industrial waste). About 1.7 percent was incinerated.

B. Methodology

The preferred approach for determining methane emissions from landfills would be to measure the emissions from each operating and closed landfill in Montana. However, such an approach is impracticable. A more practical approach is to estimate emissions on the basis of several assumptions about the average composition of landfilled waste and environmental conditions.

The State Workbook (EPA, 1995) methodology estimates methane emissions from total waste in-place based on total population and population growth rates, per capita waste generation rates, portion of waste landfilled, number of large and small landfills (greater or less than 1.1 million tons in-place), annual rainfall, and the amount of flared or vented methane. This method was used for this inventory.

Total waste in-place in Montana was determined based on 1990 tonnages reported for all MSW landfills (Class II). We assumed that all landfills were operating for the past 30 years. We applied the State Workbook growth correlation factor for Montana (based on average annual 1 percent population growth rate) during the 30-year period. Total waste in-place was computed to be 17,058,414 tons.

In Montana, four landfills are classified as large (each containing more than 1.1 million tons waste in-place): the Cascade County High Plains landfill, the Flathead County landfill, the Missoula landfill, and the City of Billings landfill. Slightly less than half (48 percent) of the total waste in-place in Montana landfills is estimated to be in the large landfills.

The moisture content of a landfill affects the rate of methane generation. Landfills in arid climates typically produce less methane per unit waste than landfills in less arid climates. All of Montana is considered to be arid (less than 25 inches of annual precipitation).

Material in Class III landfills in Montana is estimated to be 4.3 percent by weight of that in MSW landfills or approximately 733,512 tons of waste in-place for the 30-year period. The State Workbook method assumes that the average organic content at MSW landfills is 65 percent while that of Class III type landfills is 15 percent. Waste in class III landfills in Montana is mainly from the agriculture and forestry sectors, therefore, the low organic content percent is not a valid assumption for Montana. Instead, we assumed that the organic content of Class III landfills is similar to that of municipal solid waste landfills. In addition, we assumed that the conversion rate from waste in-place to methane generation is the same for all landfills.

The step-by-step method for estimating methane emissions from landfills is presented below.

1. Estimate waste in-place at all MSW landfills.

30 years x 657,357 tons (1990 total tonnage reported) x 86.5 percent (population correction factor)
= 17,058,414 tons of waste in-place all municipal landfills in Montana.

2. Estimate waste in-place in "large" and "small" MSW landfills.

EPA (1995) defines "large" as greater than 1.1 million tons waste in-place. From 1990 Class II landfill data and assuming operation for 30 years, four landfills totaling 8,188,039 tons are classified as "large" landfills (average 2,047,010 tons each large landfill).

All other landfills (totaling 8,870,375 tons) are classified as "small" (less than 1.1 million tons waste in-place).

3. Estimate waste in-place in Class III.

Multiply 17,058,414 tons (total in MSW landfills) x .043 (percent waste in Class III)
= 733,512 tons waste in-place in Class III landfills.

4. Identify Montana as an arid state.

Less than 25 inches average annual rainfall in Montana.

5. Estimate CH_4 generated at "small" landfills.

a. Multiply 0.27 ft3/ton/day (small arid landfill conversion factor) x 8,870,375 tons
= 2,395,001 ft3/day CH_4 generated.

b. Multiply 2,395,001 ft3/day CH_4 generated x 0.0077 (tons CH_4/yr)/ (ft3/day) (to convert waste in-place to annual methane emissions in tons)
= 18,441 tons CH_4 generated from small landfills.

6. Estimate CH_4 generated at "large" landfills.

a. Multiply 4 (number of large landfills) x [419,000 (large landfill generation constant) + {0.16 ft3/ton/day large arid landfill conversion factor) x 2,047,010 (average tons per large landfill)}]
= 2,986,086 ft3/day CH_4 generated.

b. Multiply 2,986,086 ft3/day CH_4 x 0.0077 (tons CH_4/yr) /(ft3/day) (to convert waste in-place to annual methane emissions in tons)
= 22,993 tons CH_4 generated from large landfills.

7. Estimate CH_4 generated at Class III landfills.

a. Multiply 0.27 ft3/ton/day (assume same as small arid landfill conversion factor) x 733,512 tons
= 198,048 ft3/day CH_4 generated.

b. Multiply 198,048 ft3/day CH_4 generated x 0.0077 (tons CH_4/yr)/(ft3/day) (to convert waste in-place to annual methane emissions in tons)
= 1,525 tons CH_4 per year from Class III landfills.

8. Estimate total tons of CH_4 generated in 1990 by adding small and large MSW and Class III landfill totals.

18,441 tons CH_4 from small landfills + 22,993 tons CH_4 from large landfills + 1,525 tons CH_4 from Class III landfills
= 42,959 tons of CH_4 generated in 1990 in Montana.

9. Subtract tons of flared methane in 1990.

No CH_4 flaring in 1990.

10. Multiply by oxidation factor to determine total tonnage of emitted CH_4.

42,959 tons of CH_4 x 0.9 (oxidation factor)
= 38,663 tons of CH_4 emitted from landfills in Montana in 1990.

C. Data Sources

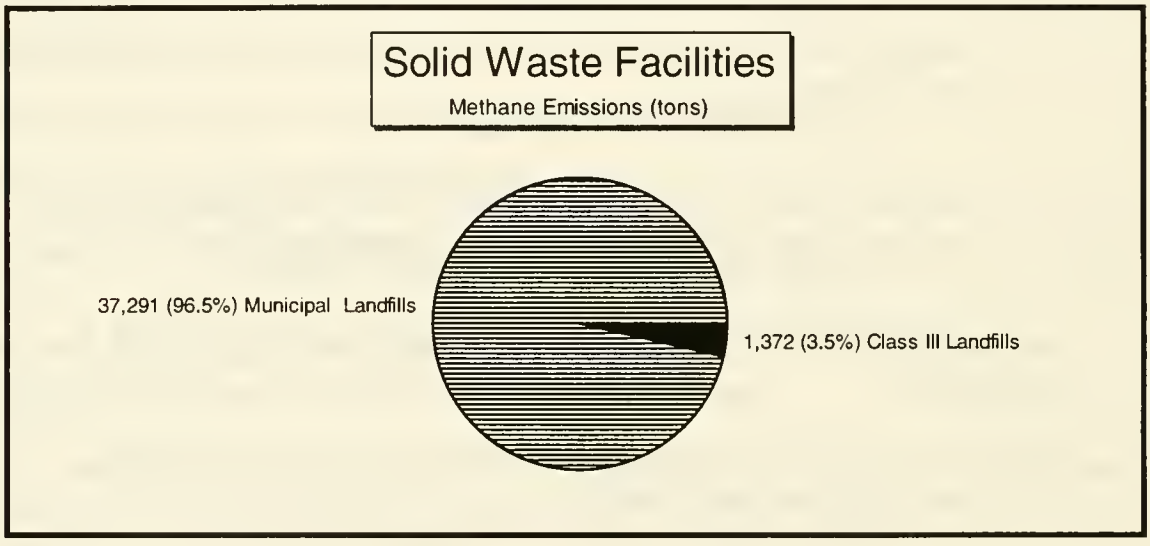
Pat Crowley (1996) provided 1990 tonnage data for Class II landfills, reviewed assumptions made in estimate methodology, and reviewed solid waste chapter results. The Montana Integrated Solid Waste Management Plan (MDHES, 1994) was referenced for background information and as comparison for Montana solid waste generation rates.

D. Emissions Estimates

Landfills in Montana in 1990 generated 42,959 tons of methane. After adjusting for soil oxidation, methane emissions from landfills totaled 38,663 tons of methane. Municipal solid waste landfills contributed 37,291 tons of methane while Class III landfills contributed 1,372 tons of CH_4. Figure 5.3. In terms of per capita emissions, Montana residents contribute an average of 97 pounds of methane per person per year from solid waste disposal. National per capita methane emission rates range from 63 to 92 pounds per year (Center for Energy and Environmental Policy, 1995).

A molecule of methane has 24.5 times the global warming potential of a molecule of carbon dioxide. Greenhouse gas emissions from municipal solid waste and Class III waste disposal are equivalent to about 947,244 total tons of carbon dioxide or 2,370 pounds of carbon dioxide per person for 1990 in Montana.

Figure 5.3. Methane Emissions from Solid Waste Facilities.



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Chapter 6. Land Use Related Emissions and Sinks

I. Summary

Humanity's changing uses of the land influence greenhouse gas emissions. Carbon dioxide (CO_2) is the largest single contributor to global warming, so the most important modifications to land use are those that significantly affect the carbon budget. Much carbon is absorbed into natural carbon sinks in Montana including lake sediments, soils, wetlands, and growing trees. Forests and rangelands sequester or take up and store atmospheric carbon in both biomass and soil. From a greenhouse gas perspective, the most important human caused land use are those that create or reduce forest lands (DOE/EIA, 1995).

Forests serve as both sources of carbon emissions (decay, fires and timber harvest) and as carbon sinks which bind up carbon in stems, branches, needles and roots. As in several other carbon inventories in forested states, this inventory indicates that carbon storage in forests is significant. Natural carbon storage is reported separately from carbon emissions and from storage which result from human land management activities, such as fire suppression. Fire suppression is thought to have increased the stocks of forest biomass by more than one-third above those present in pre-European times (Sedjo, 1996).

Because forest growth is a natural process, carbon sequestration from annual non-managed growth is reported separately from greenhouse gas emissions from human-caused land management activities. In Montana in 1990, approximately 27.4 million tons of carbon dioxide were sequestered by natural forest biomass growth. In addition, approximately 12.8 million tons of carbon dioxide sequestration are attributable to human fire suppression actions which have reduced the rate of burning of these biomass accumulations and the release of stored carbon.

Greenhouse gas emissions and sinks were estimated from the management of Montana forests and conversion of cultivated lands to grasslands. Emissions from forest management include about 15.3 million tons of carbon dioxide from forest harvest and insect and decay on commercial forest lands. Timber harvest results is storing about 36 percent of these emissions in wood products. The remaining 64 percent is emitted over time as carbon dioxide through either combustion or decay. The net release of carbon dioxide into the atmosphere is about 9.8 million tons.

The conversion of cultivated lands to grasslands was also estimated. Unusually high acreages of croplands were converted to grasslands because of the temporary effects of the Conservation Reserve Program. Estimates of carbon dioxide storage from 1990 Montana cropland conversions to grasslands are 617,300 tons.

II. Background

Photosynthesis is the mechanism driving forest carbon cycling. Every green plant extracts carbon dioxide from the atmosphere, separates the carbon atom from the oxygen atoms, returns the oxygen to the atmosphere, and uses the carbon to make biomass in the form of roots, stems, and foliage. U.S. forests removed a net 123 million metric tons (mmt) of carbon in 1990, including the net 12 mmt sequestered in wood products and the net 15 mmt sequestered in landfilled wood product waste (DOE/EIA, 1995). A fraction of dead vegetation accumulates as soil, and large quantities of roots die and slough off annually, sequestering additional carbon in the ground. As carbon dioxide concentrations increase, rates of forest photosynthesis in the northern Rocky Mountains are also expected to increase substantially (6 to 45 percent according to McGuire and Joyce 1995), so forests accumulate carbon and partially affect the increase of atmospheric carbon dioxide during periods of global carbon dioxide buildup.

Montana lands with forest cover and lands capable of growing forests totaled 22.2 million acres, covering approximately one-quarter of the state in 1990. All these lands are classified as forest lands, even if they currently lack forest cover. To provide a comparison, roughly 14.6 million Montana acres (one sixth of the state) were cultivated for agricultural crops in 1990. Most forests are located west of the Continental Divide, where they are influenced by moist Pacific coast climates. East of the divide, forest vegetation is affected by drier more extreme continental climates, resulting in scattered, slow growing forests. Total acreage in Montana in 94.2 million.

Montana forests are primarily composed of three species of trees. Douglas fir is the most common species, comprising about 27 percent of the state's total forests (Table 6.1). Lodgepole pine and ponderosa pine are the next most common species, comprising about 18 and 13 percent of the forest. About 75 percent of Montana forest lands are classified as commercial forests, meaning they are legally available for logging and have forest growth rates of at least 20 cubic feet of wood per acre per year (a minimum rate of productive growth for commercial uses). Because of their management status (mainly as wilderness and parks) about 15 percent of Montana forests are managed for aesthetic purposes and are not available for logging (reserved from commercial uses). Approximately 10 percent of Montana forests are noncommercial forests, meaning that these lands are currently incapable of growing 20 cubic feet per acre per year, or have not regenerated into new forests (following logging or fires) (Table 6.1).

Montana's commercial forests (15.9 million acres) are routinely inventoried to plan for possible future logging. Montana's commercial forests are inventoried on the basis of acreages and the amount of marketable commercial wood they contain (millions of cubic feet of commercial softwood volume). Since 1952, Montana commercial forest volumes have consistently remained near 27.5 million cubic feet (Table 6.2). Montana commercial volumes include government forests, private nonindustrial forests, and industrial forest lands.

Table 6.2 **Montana Forest Volumes - Growing Stocks on Commercial Forest Lands for Years 1952 to 1992 (millions of cubic feet of commercial softwood).**

	1952	1962	1977	1987	1992
Montana	27,367	29,793	27,691	27,611	27,702

(from Powell et al. 1993)

Table 6.1 Forest and Woody Biomass Stocks Average 1989 to 1992 Annual Increments

Land Use Biomass Changes

	Column A Area of Biomass & Forest Stocks (1,000 acres)	Column B Annual Growth Rate (Cf/Ac/Yr) (from O'Conner & O'Brien, 1993)	Column C (A*B) Annual Biomass Increment (1,000 CU.FT. wood/acre/yr)	Column D Ratio of Total Above-Ground Volumes to Merchantable Volume (Tbl 1.1 USEPA,1995)	Column E Carbon Factor Conversions (Index #'s from Table 1.2 USEPA, 1995)	Total Carbon (C*D*E) Total "C" Intake Increment (1,000 tons "C" per year)	Molecular Weight Conversion Factor	**Total CO_2**
Commercial Timberlands (>20 cu. ft./acre/yr)								
Douglas Fir	5,474	36.32	198,801	1.898	15.11	**2,851**		
Lodgepole Pine	3,585	40.41	144,849	1.898	11.86	**1,630**		
Ponderosa Pine	2,603	22.93	59,697	1.898	13.29	**753**		
Other Forest Species	3,638	34.84	126,742	1.898	13.42	**1,614**		
All Commercial	15,300	34.66	530,089	1.898	13.61	**6,848**		
Total Commercial Forest	15,300	34.66	530,364	1.898	13.61	**6,848**		
Productive Reserved Forest	1,728	26.00	44,925	1.898	13.61	**306**		
Other Forested Lands woodland<20 Cu.ft./acre/yr.	5,184	8.67	44,921	1.898	13.61	**306**		
Totals	**22,212**	**27.92**	**620,210**	**1.898**	**13.61**	**7,460** Tons C (1,000's) Storage in 1990	44/12	**27,352** Tons CO_2 (1,000's) Storage in 1990

1990 Annual Pounds of Carbon Storage/acre: 7,460,000 tons / 22,212,000 acres = 671,684 pounds/acre annually

Acreages Averaged from 1987 data and 1992 data
Average of 1987 data (Waddell, Oswald, and Powell, 1989) and 1992 data (from Powell, Faulkner, Darr, Zhu, and MacCleery, 1993)

The only commercial forest subcategory with substantial forest volume declines are industrial forest lands (comprising 1.6 million commercial acres), which have experienced a one-third volume decrease over the past 40 years (Powell et al., 1993). Over the most recent five year period, annual increases in total Montana commercial forest volumes have averaged 18.2 million cubic feet per year (equal to 840,000 tons of carbon dioxide sinks annually), which is a .066 percent annual increase in total commercial forest volume estimates, probably well within the sampling errors of these inventories.

The latest Montana forest inventory (1992) is incomplete, so data from earlier inventories are included in the most recent estimates (Conner and O'Brien, 1993). Data from ongoing surveys of forest and land use activities are generally used, in order to provide for better comparisons with expected future forest inventory compatibility for carbon dioxide estimates. Thus, this present study generally uses data available from the ongoing forest inventories conducted on a five year cycle by the U.S. Forest Service and state forest agencies. In the future, these forest inventories would be expected to provide comparable inventory information (in the years 1997 and 2002) for subsequent greenhouse gas inventory estimates.

Land use changes from farming and other agricultural activities have varied substantially over the past 70 years. While there have been moderate declines in total lands within Montana farm boundaries over the past 40 years (Table 6.3), since 1950 there have been relatively small changes in the acreages of Montana's two largest cultivated crops, wheat and hay. Most abandoned croplands were historically grasslands, so this analysis assumes they would revert to their prior condition as grasslands.

Table 6.3. Long-term Trends in Montana Farmlands and Croplands - (Three Year Average at Listed Year, in Thousands of Acres).

Montana	1920	1930	1940	1950	1960	1970	1980	1990
Land In Farms	na	64,700	60,200	64,900	66,700	64,200	61,900	60,500
All Wheat (planted)	3,757	4,669	3,910	5,844	4,198	3,981	5,998	6,043
All Hay (harvested)	1,653	2,110	1,807	2,263	2,163	2,391	2,320	2,250

(from Montana Department of Agriculture and Montana Agricultural Statistics Service. 1978 - 1992)

Because agricultural cropland changes were relatively small and because forest ecosystems contain substantially more biomass than grasslands, this greenhouse gas inventory focuses primarily on forest land changes and forest carbon storage changes. A brief estimate of the effects of recent cropland reversions to natural grasslands is presented in order to provide a preliminary estimate of greenhouse gas effects of agricultural cropland reversions to grasslands.

III. Methodology

This study generally follows the EPA States Workbook Methodologies for Estimating Greenhouse Gas Emissions (EPA, 1995) with moderate modifications. These methodologies include the following steps to estimate total and net carbon dioxide flows (emissions and storage) from vegetative biomass changes.

Carbon estimates for forest and cropland management changes are developed for land use changes around the year 1990. These carbon estimates are converted into land use carbon dioxide storage and emission equivalents. Forest biomass volumes were measured in thousands of cubic feet (mcf) of commercial forest products. Since these commercial forest volume estimates include only those portions of the tree that can be converted to human uses, they do not include many above-ground forest biomass components, such as small branches, stumps, needles and unusable tree boles. Thus, the commercial volume inventories measure only 53 percent of total above-ground forest biomass from inventoried commercial forests (EPA, 1995). Therefore, all commercial forest volume estimates are increased by a factor of 89.8 percent to provide a complete estimate of the total above-ground biomass (see U.S. EPA 1995 for details). Because there are no direct estimates of below-ground forest volumes (roots), only above-ground forest volume estimates were prepared. This inventory does not provide any estimates of changes in below-ground forest biomass (such as roots).

Step 1. Storage of Above-Ground Carbon in Natural Forest Growth Sinks.

Assumptions used in these calculations include:

671.68 lbs of C/acre is the average annual carbon uptake above ground on Montana forest lands (Table 6.3).

22,212,000 acres of Montana lands were classified as forested in 1990.

CO_2 storage = (forest Carbon uptake per acre) x (1 ton/2,000 lbs) x (number of forest acres) x (44 ton CO_2/12 ton C).

CO_2 storage = (671.68) x (1/2,000) x (22,212,000) x (44/12)

= **27,351,700 tons of potential CO_2 storage (sink) in 1990 from annual Montana natural forest growth.**

Step 2. Net Emissions from Above-Ground Carbon Removals from Management Activities.

Assumptions used in these calculations include:

249,728 thousand cu. ft. (mcf) of forest biomass were removed by human activities from Montana forests in 1990, including 222,237 mcf that were converted into lumber and other wood products (Conner and O'Brien, 1993).

73,900 thousand cu. ft. (mcf) of forest biomass was removed by timber harvest and lost to fire, insects and decay in 1990 (commercial forests only) (Conner and O'Brien, 1993).

Total forest biomass can be estimated by increasing commercial forest volumes by 89.8 percent to estimate total above ground forest biomass (EPA, 1995 from Birdsey, 1992). The same factor is applied to estimates of commercial volume losses due to fire, insects and decay.

2a. Gross CO_2 Emissions

= (Volumes of forest removals (in 1,000 cu. ft.)) x (total above-ground volume to removed volume ratio) x (carbon conversion index from Table 6.3) x (1 ton/2,000 lbs) x (44 ton CO_2/12 ton C)

= (249,728 + 73,900 cu. ft.) x (100 percent + 89.8 percent) x (13.61 conversion index) x (1/2,000) x (44/12)

= **15,326,000 tons CO_2 lost from forest biomass (as wood products and waste).**

2b. CO_2 Conversions of Forest Biomass into Forest Products (to sink)

= (Volumes of commercial forest biomass removed to wood processing plants -in 1,000 cu. ft.) x (carbon conversion index from Table 6.3) x (1 ton/2,000 lbs) x (44 ton CO_2/12 ton C)

= (222,237 cu. ft.) x (13.61 conversion index) x (1/2,000) x (44/12)

= **5,545,000 tons of CO_2 stored in wood products.**

2c. Net CO_2 Forest Emissions from Management Activities

= Total volumes of forest removals (CO_2 tons) - Forest biomass conversions into wood products (in CO_2 tons).

= 15,326,000 tons CO_2 - 5,545,000 tons CO_2

= **9,781,000 tons CO_2 net forest biomass emissions from management activities.**

Step 3. Forest Land Acreage Increases Causing Carbon Storage.

Assumptions used in these calculations include:

Montana commercial forest lands total 14,737,000 acres in 1987 and 15,863,000 acres in 1992, for an annual increase of 225,200 forested acres per year (Conner and O'Brien, 1993). This analysis assumes that newly forested lands store carbon at the same rate as lands abandoned in the last twenty five years (EPA Table 10-6).

58.4 tons soil C/acre (EPA, 1995)
50 % of carbon is emitted from the soil (EPA, 1995)
29.2 ton C/acre emitted (58.396 x .50)
25 year average elapsed period (EPA, 1995)

CO_2 emit/storage = [(forest acres lost or gained) x (tons C/acre released) / (average annual elapsed period)] x (44 ton CO_2/12 ton C)

= [(225,200 acres gained) x (29.2 ton C/acre) / 25 years] x (44/12)

= 964,400 tons of CO_2 forest land storage (sink) from forest land increases

Step 4. Conversions of Cultivated Lands to Grasslands.

Assumptions used in these calculations include:

Net CO_2 annual release from natural grasslands = 0.49 ton C/acre (WDNR, 1993)
Net CO_2 annual release from cultivated croplands = 1.10 ton C/acre (Henderson, 1993)

Cultivated Cropland Changes

	Montana croplands used for crops (1,000's of acres)		
	Irrigated	Dryland	Total Cropland
1987 NRI Inventory	1,997	13,324	15,321
1992 NRI Inventory	1,978	11,963	13,941
1990 Annual Change	**-3.8**	**-272.2**	**-276** per year

(National Resources Inventory - (NRI) - data from USDA, 1994 and 1996)

CO_2 Emitted or Stored = (annual acres plowed or reverting) x [(tons/acre of C emission from cultivated croplands) - (tons/acre of C emission from natural grasslands)] x (44 CO_2/12 C)

CO_2 (Storage) = (276,000 acres) x [(1.10 tons C/acre) - (0.49 ton C/acre)] x (44 CO_2/12 C)

= 617,300 tons CO_2 grassland storage (sink) in year 1990 from conversion of 276,000 acres cultivated cropland to grass land.

Step 5. Retention of Forest and Range Biomass Due to Human Fire Suppression Efforts

As a final land use issue, we estimated the reduction in carbon dioxide emissions due to fire suppression of forest and range land fires in Montana. This method was not presented by EPA in the State Workbook, but is a significant human-caused carbon sink in Montana.

Assumptions used in these calculations include:

Natural fire acreage of Montana wildlands burned annually	= 1,204,000 acres
Annual 1990 average wildfire acreage burned with human suppression	= 219,126 acres
Annual anthropogenic ecosystem biomass storage is effectively increased	= 984,874 acres
Above ground forested ecosystem biomass stock (Table 6.3)	= 32.912 tons d.m./acre
Above ground rangeland ecosystem biomass stock (EPA, 1995)	= 2.25 tons d.m./acre

Approximately 1.2 million acres of Montana forest and range lands (roughly 1 percent of the state) would be expected to be burned annually by fire, (estimated from Barrett, et. al., in process). Montana forests have an average natural cycle of burning every 95 years, or a statewide average of 408,000 burned acres annually. Human fire suppression actions have reduced this natural forest burned acreage by 334,000 acres annually. Montana rangelands have a historic natural fire cycle of 25 years, or an expected 796,000 acres would naturally burn annually. Human suppression activities have reduced burned rangeland acreage by 651,000 acres annually below historic natural levels. In total, human fire suppression efforts have reduced Montana burned acreage by 82 percent below historically occurring 1.2 million acre burn levels resulting in an average of 219,126 forest and range land acres burned annually during the 1988 to 1992 period (USDA Forest Service, undated).

Human suppression of forest and rangeland fire has become more difficult as plant biomass accumulates on-site (becoming potential fuel for fires). This increased biomass (fuel loadings) substantially increases fire fighting difficulty, resulting in increased fire burn acreages over the last 20 years (Arno, 1996). Future fire management is expected to use human prescribed fires to reduce forest and rangeland fuel loadings to more natural levels. This will reduce the size of the biomass sink.

Human fire suppression efforts have reduced the acreage of forest and rangeland burned by approximately 985,000 acres below historic natural fire levels. These reduced levels of burning have reduced CO_2 emissions by the following amount:

CO_2 fire = [(per acre Carbon loadings) x (percent of biomass burned and emitted to emission atmosphere from fires) x (number of acres with reduced fires)] reductions x (44 ton CO_2/12 ton C).

= [(32.912 tons/acre from forest lands x 25% x 334,000 reduced burned acres) + (2.25 tons/acre from rangelands x 50% x 651,000 reduced burned acres)] x (44 ton CO_2/12 ton C)

= **12,761,900 tons of annual CO_2 burning emissio**

Background assumptions, rationales for methodologies used in steps 1 through 4, and data sources are discussed in detail in Appendix A. Data sources for Step 5, fire suppression, (Barrett et. al., in process and USDA Forest Service, undated) differ from data sources used in Steps 1 through 4.

IV. Data Sources

Background assumptions, rationales for methodologies used in steps 1 through 4, and data sources are discussed in detail in Appendix A. Data sources for Step 5, fire suppression, (Barrett et. al., in process and USDA Forest Service, undated) differ from data sources used in Steps 1 through 4.

V. Sink and Emissions Results

Natural forest growth in 1990 resulted in an estimated 27,351,700 tons of carbon dioxide storage. For comparison purposes it is interesting to note that this uptake is greater than emissions from all energy use in Montana. Since this uptake is naturally occurring and does not involve any human activities, this total is reported separately (see Step 1) from the other land use carbon dioxide changes which result from human activities.

Greenhouse gas emissions from human land use activities in 1990 include four areas. The first is the total emissions from forest harvest, fire, insect and decay minus total emissions from carbon storage in wood products. Second, carbon storage from increases in forest land acreage. Third, carbon storage from conversion of cultivated lands to grasslands. Fourth, reduced carbon emissions resulting from human fire control activities. The total combined effects of these four human activities are about 4.6 million tons of annual carbon dioxide storage.

Total carbon dioxide changes = Net Forest Land Emissions (net emissions from forest activities and forest biomass conversions to wood products) (Step 2)
+ Increased Forested Acreage Storage (Step 3)
+ Cultivated Cropland to Grassland conversions (Step 4)
+ Reduced Yearly Emissions from Fire Suppression Actions (Step 5)

= - 9,781,000 ton net emissions
+ 964,400 ton storage
+ 617,300 ton storage
+ 12,761,900 ton storage effect

= **4,562,600 tons of carbon dioxide storage from human land use activities**

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Chapter 7. Results and Recommendations

I. Results

Greenhouse gas emissions are rarely measured directly but are estimated on the basis of data collected for other purposes. Both the available information and the assumptions used to calculate greenhouse gas emissions are of varying reliability. In the case of carbon dioxide (CO_2), emissions are calculated by multiplying reported energy consumption by the estimated carbon content of fossil fuels. This provides a fairly reliable estimate, in that both energy statistics and estimates of carbon content are accurate within a few percent (DOE/EIA, 1995). For methane (CH_4) and nitrous oxide (N_2O), however, emissions are generally inferred by extrapolating experiments conducted on a small number of samples across a large sometimes heterogenous population. As a result, methane and nitrous oxide emissions estimates are much more uncertain than carbon dioxide emissions estimates.

In Montana for 1990, human-caused greenhouse gas emissions from energy, production processes, agriculture and waste totaled approximately 30 million tons of carbon dioxide equivalent. Net emissions from timber harvesting in Montana equaled about 10 million tons of carbon dioxide, while net sequestration from land management activities equaled about 14.6 million tons of carbon dioxide. Emissions from human activities in Montana were determined for the major gases and sources, land use is reported separately. Table 7.1.

This inventory determined the relative carbon dioxide equivalent percent of the four primary greenhouse gases emitted as a result of human activity. Excluding land use, approximately 74 percent of total carbon dioxide equivalent emissions in Montana are from carbon dioxide, 14 percent from methane, 2.5 percent from nitrous oxide, and 9.5 percent from halogenated fluorocarbons. Figure 7.1.

Figure 7.1. Percent of Montana Total Greenhouse Gas Emissions by Gas, 1990.

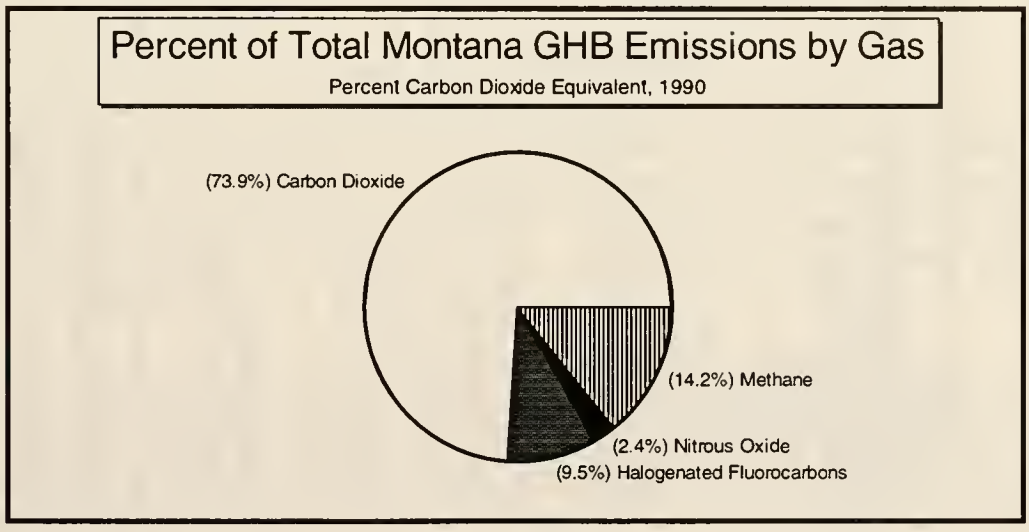
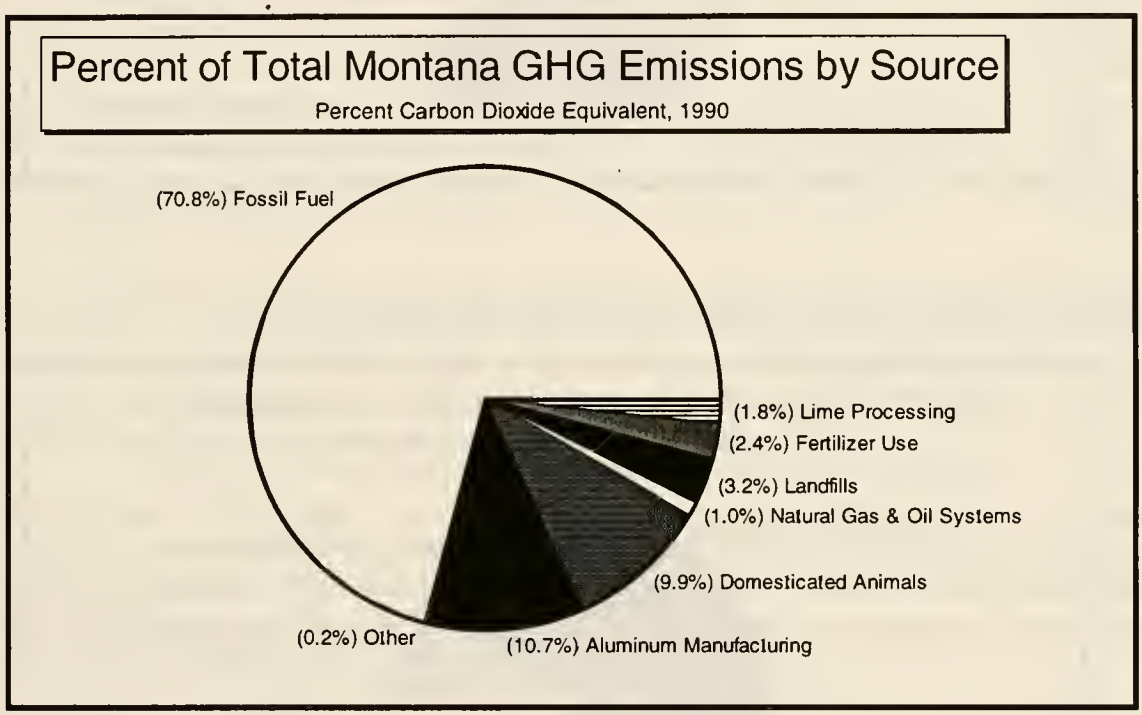

Percent of Total Montana GHB Emissions by Gas
Percent Carbon Dioxide Equivalent, 1990
(73.9%) Carbon Dioxide
(14.2%) Methane
(2.4%) Nitrous Oxide
(9.5%) Halogenated Fluorocarbons

Table 7.1. Major Human Caused Greenhouse Gas Emissions Estimates for Montana in 1990 (Tons).

SOURCE Global Warming Potential	CO_2 (1 GWP)	CH_4 (24.5 GWP)	N_2O (320 GWP)	HFC (8400 GWP)	CO_2 Equivalent	Percent
Energy Related						**Total 71.9**
Fossil Fuel Combustion						
Residential	3,150,490				3,150,490	10.6
Commercial	2,372,080				2,372,080	8.0
Industrial	8,846,170				8,846,170	29.7
Transportation	6,440,940				6,440,940	21.6
Other Electric	259,210				259,210	0.9
Biomass Fuel Combustion	37,300				37,300	0.1
Natural Gas and Oil Systems		11,572			283,500	1.0
Coal Mining		776			19,000	0.0
Production Processing						**Total 12.5**
Lime Processing	521,000				521,000	1.8
Aluminum Manufacturing	355,300			337	3,186,100	10.7
Agriculture Related						**Total 12.3**
Domestic Animals		120,110			2,942,700	9.9
Fertilizer Use			2,254		721,300	2.4
Waste Related						**Total 3.3**
Waste Water Treatment		1,076			26,400	0.1
Landfills		38,663			947,200	3.2
TOTAL (tons greenhouse gas)	21,982,490	172,197	2,254	337	29,753,400	
TOTAL (tons CO_2 equivalent)	21,982,490	4,218,827	721,300	2,830,800	**29,753,400**	
PERCENT	**CO_2 73.9%**	**CH_4 14.2%**	**N_2O 2.4%**	**HFC 9.5%**		

Emissions were inventoried by major source categories; energy, production processes, agriculture, and waste management. The combustion of fossil fuels is the major source of greenhouse gas emissions in Montana, accounting for 70.8 percent of emissions. Aluminum manufacturing accounts for 10.7 percent of carbon dioxide equivalent emissions in the form of halogenated fluorocarbons. Emissions from domesticated animals is the next largest source at 9.9 percent. All other sources including landfills, fertilizer use, lime processing, natural gas and oil processing, coal mining and biomass combustion comprise about 8.6 percent of Montana's greenhouse gas emissions. Figure 7.2.

Figure 7.2. Percent of Montana Total Greenhouse Gas Emissions by Source, 1990.



Excluding land use sinks and emissions, the use of petroleum accounts for 37.7 percent, coal 24.4 percent, and natural gas 8.7 percent of fossil fuel based greenhouse gas emissions in Montana in 1990. The next largest source of greenhouse gas emissions in Montana is halogenated fluorocarbons from aluminum manufacturing accounting for 10.7 percent of emissions. Methane emissions from domesticated animals follows at 9.9 percent. All other sources combined total 8.6 percent of greenhouse gas emissions. Figure 7.3.

Fossil fuel combustion by use sector is also interesting to identify. Energy emissions were broken down into the residential sector (10.6 percent), commercial sector (8.0 percent), industrial sector (29.7 percent), other electric uses (0.8 percent), and the transportation sector (21.7 percent). The remaining carbon dioxide equivalent emissions are from other non-energy sources, including aluminum production (10.7 percent), domesticated animals (9.9 percent) and all other sources (8.6 percent). Figure 7.4.

Figure 7.3. Major Montana Greenhouse Gas Emissions, Energy by Source.

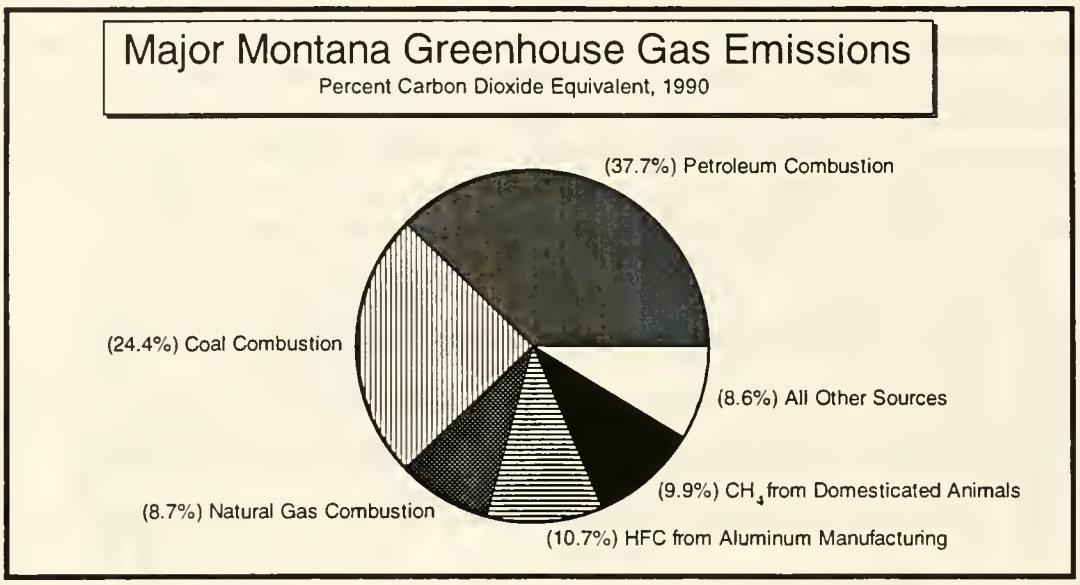
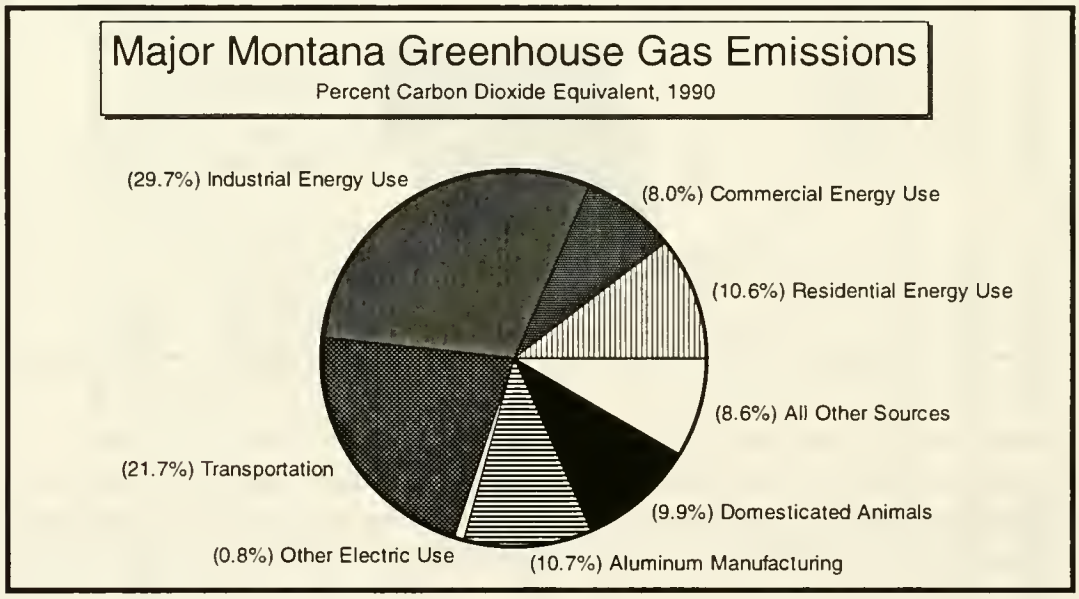

Major Montana Greenhouse Gas Emissions
Percent Carbon Dioxide Equivalent, 1990
(37.7%) Petroleum Combustion
(24.4%) Coal Combustion
(8.6%) All Other Sources
(9.9%) CH_4 from Domesticated Animals
(8.7%) Natural Gas Combustion
(10.7%) HFC from Aluminum Manufacturing

Figure 7.4. Major Montana Greenhouse Gas Emissions, Energy by Use.



Land use related greenhouse gas calculations are complex and were considered separately. Land management activities serve as both a source of carbon emissions (mainly through timber harvesting) and as a carbon sink (through fire suppression). Emissions from timber harvest and wood waste released about 15 million tons of carbon dioxide, however, about 5 million tons were stored in wood products for a net emission of 10 million tons. Increased forest acreage and the conversion of cultivated crops to grassland sequestered about 1.5 million tons of carbon dioxide. Sequestration or storage of carbon in the form of forest fire suppression is temporary and calculated to be about 13 million tons of carbon dioxide. At some time, the stored carbon will burn or decay and result in carbon emissions.

Montana is a net exporter of energy. Montana exports about 63 million tons of carbon dioxide emissions from raw fuel, about 65 percent is raw coal for electricity generation out of state. Montana also exports about 9 million tons of carbon dioxide emissions attributable to coal-generated electricity. Montana imports about 23 million tons of carbon dioxide emissions, about 90 percent is in the form of crude oil. Net exported carbon dioxide emissions from interstate energy and electricity transfers equals about 49 million for 1990.

II. Comparisons with National and State Inventories

Among the nations of the world, the U.S. is the largest single emitter of greenhouse gases. In 1990, the U.S. was responsible for 22 percent of the worldwide carbon dioxide equivalent emissions (DOE/EIA, 1993), but contains only 5 percent of the world's population. Total human-caused emissions of greenhouse gases in the U.S. in 1990 were 5,929 million tons of carbon dioxide equivalent which increased to 6,028 million tons by 1993 (DOE/EIA, 1995). Average U.S. per capita emissions of carbon dioxide equivalent greenhouse gases were 23.8 tons in 1990. The U.S. totals and average are based on Department of Energy, Energy Information Administration (1995) data which may compute emissions differently than procedures identified for state use by EPA (1995).

In the U.S., approximately 85 percent of total carbon dioxide equivalent greenhouse gas emissions are from carbon dioxide, 10 percent from methane, 2 percent from nitrous oxide, and about 3 percent from halogenated fluorocarbons (DOE/EIA, 1995). Of carbon dioxide emissions in the U.S., 98.5 percent are caused by the combustion of fossil fuels. Of methane emissions in the U.S., 18 percent are from domesticated animals and 39 percent are from landfills (DOE/EIA, 1995).

Excluding land use, carbon dioxide equivalent greenhouse gas emissions in Montana are approximately 74 percent from carbon dioxide, 14 percent from methane, 2.5 percent from nitrous oxide, and about 9.5 percent from halogenated fluorocarbons. In Montana 96 percent of carbon dioxide emissions are caused by the combustion of fossil fuels. Sixty-eight percent of methane emissions in Montana were from domesticated animals while 22 percent were from landfills.

Montana's greenhouse gas emissions differ from the national averages in several ways. First, Montana's aluminum industry is a significant contributor to greenhouse gas emissions. Carbon tetrafluoride and carbon hexafluoride from the aluminum production process account for about 10.7 percent of total carbon dioxide equivalent emissions from the state. In addition, about half of the electricity production in Montana comes from hydropower, which emits essentially zero greenhouse gases. These factors help explain the difference between national and Montana emission statistics for carbon dioxide and halogenated fluorocarbons. Second, agriculture is a major industry in Montana, while the state's population is comparatively low. This reverses the relative contribution of methane from domesticated animals and landfills for Montana compared to the nation as a whole.

The Montana emission totals can be compared with other state inventories completed under grants from the Environmental Protection Agency. However, Global Warming Potentials (GWP) are constantly being revised and several state inventories were completed using different GWP's. In addition, land use was treated differently among several states. Therefore, emissions from land use activities were not included in the comparisons with other states. To directly compare inventories, emissions data

were multiplied by consistent global warming potentials (GWP); methane 22, nitrous oxide 270, and CFC and HFC's 5400. Using these GWP, Montana greenhouse gas emissions were compared with results from several states with completed inventories, Washington State Energy Office (1995), Oregon Department of Energy, (1995), Minnesota Center for Energy and Environment (1995), and Wisconsin Department of Natural Resources and the Public Service Commission of Wisconsin, (1993). Emissions comparisons with halogenated fluorocarbons (HFC) and chlorofluorocarbons (CFC) are presented in Table 7.2. Comparative totals and per capita averages between states are misleading in this table. Minnesota and Wisconsin reported HFC and CFC emission estimates based on U.S. per capita emissions multiplied by state population, while Montana, Washington and Oregon did not include this estimate in their state inventories.

Table 7.2. Greenhouse Gas Emissions Camparisons, 1990.

	CO_2 GWP=1	CH_4 GWP=22	N_2O GWP=270	HFC & CFC GWP=5400	Total CO_2 Equiv. (Tons)	1990 Population	CO_2 Equiv. Tons/person
Montana	21,982,000	3,784,000	607,500	1,819,800	28,193,300	799,000	35.3
Washington	130,404,000	10,670,000	858,600	11,626,200	153,558,800	4,867,000	31.6
Oregon	55,300,000	5,720,000	202,500	799,200	62,021,700	2,842,000	21.8
Minnesota	84,090,000	11,814,000	1,374,300	45,954,000	143,232,300	4,376,000	32.7
Wisconsin	108,157,000	14,960,000	1,836,000	78,084,000	203,037,000	4,892,000	41.5

Table 7.3 presents a more accurate comparison of state greenhouse gas emissions. Population data and emissions per capita are provided for comparisons between states.

Table 7.3. Greenhouse Gas Emissions Camparisons Excluding HFC's and CFC's.

	CO_2 GWP=1	CH_4 GWP=22	N_2O GWP=270		Total CO_2 Equiv. (Tons)	1990 Population	CO_2 Equiv. Tons/person
Montana	21,982,000	3,784,000	607,500		26,373,500	799,000	33.0
Washington	130,404,000	10,670,000	858,600		141,932,600	4,867,000	29.2
Oregon	55,300,000	5,720,000	202,500		61,222,500	2,842,000	21.5
Minnesota	84,090,000	11,814,000	1,374,300		97,278,300	4,376,000	22.2
Wisconsin	108,157,000	14,960,000	1,836,000		124,953,000	4,892,000	25.5

III. Discussion and Recommendations

The results from this inventory provide an estimate of the source, type and quantity of greenhouse gas emissions in Montana. This information lays the foundation for actions to reduce and manage emissions through sensible and cost-effective mitigation strategies. This information also has prepared Montana to respond to any national efforts to reduce greenhouse gases in a way that treats all emission sources fairly.

The next steps Montana should take to continue and expand our contribution to meet the global warming challenge include replicating the statewide emissions inventory at 5-year intervals and developing a greenhouse gas emissions action plan.

Future inventories are necessary to chart statewide emissions over time, determine trends in the different emissions categories, and quantify how emissions respond to any future policies and programs. This first inventory has determined and documented appropriate emissions methodology and data sources, developed computer spreadsheets and graphics. This background work means that future inventories would be efficient to complete and would produce results that are comparable over time.

The Montana Department of Environmental Quality has been awarded a grant from the U.S. Environmental Protection Agency Climate Change Division to develop a greenhouse gas emissions action plan. The action plan development would be a collaborative approach between state and local governments and industry. This collaborative would evaluate potential as well as current policies and programs that could reduce greenhouse gas emissions and then search for least-cost approaches to reduce emissions and establish priorities among the various options. A major component of the action plan would be to investigate market-based opportunities and incentives that reduce emissions. Several voluntary actions to report and reduce greenhouse gas emissions are ongoing in Montana. This collaborative would seek to coordinate and better document these activities and exchange information between public and private sector emission reduction and management efforts.

IV. References

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Appendix A.
Background and Assumptions for Land Use Chapter

Step 1

The acreages in column A of Table 6.1 were derived by averaging: 1) the 1987 Forest Service forest inventory data (reported in Waddell, et al. 1987) which were adjusted to match Birdsey's (1993) total Montana forested acreages (his Table 2.1) so as to be more fully compatible with the 1987 acreage estimates, productivity classes and management requirements (Worksheet 10-1c), and 2) the 1992 forest inventories from Powell, et al., 1993 (see Worksheet 10 -1c for Waddell/Birdsey, Worksheet 10 -1d for Powell, et. al., and Table 6.3 for the estimated 1990 acreage base). These forest inventory data from these two data sources were combined (averaged) in order to most accurately estimate Montana's 1990 forested acreages (see Table 6.3 for these estimated acreages).

The carbon uptake per acre is estimated from an incomplete weighted average of the total "C" stored in forests (from Worksheet 10 -1, column F) divided by the total forest acres (from Worksheet 10 - 1, column A). The carbon factor conversions numbers are from USEPA Workbook Table 1.2 - Factors to convert tree volume (cubic feet) to carbon (pounds) for three of the tree species (Douglas Fir, Lodgepole Pine, and Ponderosa Pine) listed. However, conversion factors for other tree species were not available, so they were estimated (and adjusted) from the average of these three known tree species carbon conversion factors (for the "other" Montana commercial species, for noncommercial "reserved" forest lands, and for the other forested "woodlands").

In addition, the growth rates in Table 6.1 (column B) were calculated from Conner and O'Brien, 1993, using their species growth totals (their Table 23), and their nonreserved acreage totals (their Table 10) in order to derive species specific average annual growth rates. Growth rates for reserved and other forest lands were estimated from the above information.

In reviewing this information, Montana reviewers believe that these estimates substantially overstate the growth rates and standing volumes of forest biomass on lands managed by the state of Montana (which comprise about 4 percent of the forested nonreserved lands). A second limitation is the use of 1987 inventory information in the 1993 inventories of National Forest lands (about 60 percent of Montana nonreserved forest lands) which are included in the 1993 estimates for National Forest lands. Thus, National Forest's growth estimates are based on only one inventory (1987) and are insufficient for estimating growth changes over time. Therefore, the accuracy of carbon sequestration by natural tree growth is limited. However, because tree growth is a natural process, data was presented for informational purposes only and not included in total carbon dioxide estimates.

Step 2

The total forest biomass numbers for fuel wood and miscellaneous wood product removal may be considered as very rough estimates because the data sources for these estimates are often very crude.

The fire, insect and decay removals are volume estimates for the commercial wood removals (before applying the biomass expansion factor), includes only estimates of fire, decay and insect losses occurring on commercial forest lands (the location for approximately 92 percent of the estimated 1990 biomass growth). To fully estimate all fire, insect and decay losses, the biomass loss estimates that are presented would have to be increased by an unknown amount (probably somewhere around 8 percent). However, because this amount was unknown and relatively small, no estimates of fire, insect and decay losses on noncommercial lands were included.

A second major assumption used in this analysis is that all biomass affected by fire, insects and decay is converted to carbon dioxide within one year. This assumption oversimplifies the rates of fire, insect and decay processes, which may actually take from one year (fire and direct decay/insect consumption) to ten years (decay around the infected biomass area) to 30 years (burnt stags decaying back into elements). In order to simplify these admittedly rough estimates, the presented method assumes that all these processes losses occur in the year that the inventory finds that the merchantable value of the tree volume is no longer suitable for commercial uses. This assumption probably is not a large problem when these three processes (fire, insect and decay) are relatively constant over time (no sudden surges or declines). In more steady state process cycles, the losses inventoried in one year (which will physically occur in later years) tend to average out with the physical losses recorded in prior inventory years which actually take place in the present inventoried year (steady rates of loss shifting). When the rates of fire, insect and decay are substantially variable on a multi year basis, the averaging of annual physical losses between years will overstate fire, insect and decay losses in low loss years and understate losses in high loss years and for several subsequent years.

The carbon dioxide emission processes (forest removals, fire, decay and insects) were estimated in the first portion of this step, while the second portion of this step estimates the actual forest biomass that is converted wood products, which act as another form of long-term carbon storage (as lumber, plywood, furniture, etc). These long-term wood product carbon storage sinks are accounted for in the land use inventory section of these estimates, but could just as easily be credited to the industrial products segment of these estimates (where they are actually converted into a long-term stable product).

Step 3

A simplifying assumption is that all lands converted into forest lands (1,126,000 inventoried acres between 1987 and 1992) were converted into commercial forest lands from nonforested lands. This probably is a generous assumption, since a significant portion of these lands possibly come from the nonproductive forest lands classification, and are now just beginning to have enough forest stocking and growth to justify their reclassification into the commercial forest class.

This rate of lands moving into the forested lands classification (an estimated 225,000 acres annually between 1987 and 1992) is an extraordinary rate of reforestation (if accurate). Most forest land observers feel that the changes in total forest lands is more likely due to ongoing shifts in methods and availability of forest inventory data. This recent forest acreage increase is even more remarkable in the face of well established trends toward long-term losses in commercial forest lands of 0.13 percent annually (averaging 22,000 acres annually over the past 40 years) (Powell, et al, 1993). Classification of lands as commercial forest lands is based on their present management status and the biological growth rates. This classification is unrelated to property tax assessment or other business management classifications.

Step 4

A simplifying assumption is that all lands removed from cropland production are converted to permanent grassland. A second assumption is that the average estimated cropland and grassland emission rates are accurate and apply across both dryland and irrigated land areas. The estimates developed in this section are very preliminary and will need to be refined in further efforts. The rationale for developing these admittedly rough estimates is to get a handle on the relative magnitude of cultivation land changes effects. These cropland conversion estimates are believed to be substantially inflated by large one-time effects of the Conservation Reserve Program (CRP), which enrolled approximately 2.7 million acres of Montana cropland between 1986 and 1994. This enormous cropland conversion is thought to be temporary, and some of these CRP lands may go back into crop production following expiration of their 10 year CRP contracts, beginning in 1996.

Table A. Year 1989 Forest and Woody Biomass Stocks Increment

Land Use Biomass Changes

	Column A Area of Biomass & Forest Stocks (1,000 acres)	Column B Annual Growth Rate (Dry Matter/ Acre/Year) tons	Column C (A*B) Annual Biomass Increment (1,000 tons of DM/acre/yr)	Column D Carbon Fraction of D.Mtr. (tons C/ ton D.Mtr)	Column B (revised from Birdsey, 1992) Annual Growth Rate (Tons Carbon/ Acre/Year)	Column E (C*D) Total Carbon Intake Increment (1,000 tons C per year)
Commercial Timberlands						
(>20 cu. ft./acre/yr)						
Douglas Fir	6,053				0.551	3,335
Lodgepole Pine	3,964				0.623	2,470
Ponderosa Pine	2,879				0.341	982
Other Forest Species	4,027				0.366	1,472
Total Commercial	16,923				0.488	8,258
Total Commercial Forest	16,923				0.488	8,258
Productive Reserved Forest	3,437				0.488	1,677
Other Forested Lands	91					
<20 Cu.ft./acre/yr.	2,059					
	2,150				0.391	841
Total Forested Lands	**22,510**					**10,776**

1989 Data from Res. Bul. INT-81, Conner and O'Brien, 1993

Table B. Year 1987 Forest and Woody Biomass Stocks Increment

	Column A Area of Biomass & Forest Stocks (1,000 acres)	Column B Annual Growth Rate (Tons DM/ Acre/Year)	Column C (A*B) Annual Biomass Increment (1,000 tons of DM/ac/yr)	Column D Carbon Fraction of D.Mtr. (tons C/ ton DM)	Column B (revised from Birdsey, 1992) Annual Growth Rate (Tons Carbon/ Ac/Yr)	Total Carbon (C*D) Total Carbon Intake Increment (1,000 tons C per year)
Commercial Timberlands						
(> 20 cu. ft./acre/yr)						
Douglas Fir	5,274					
85+	795				0.885	703
50 to 85	2,420				0.573	1,387
20 to 50	2,059				0.323	665
Lodgepole Pine	3,454					2,755
85+	543				1.106	600
50 to 85	1,615				0.735	1,187
20 to 50	1,296				0.439	568
Ponderosa Pine	2,508					2,355
85+	98				0.661	65
50 to 85	618				0.439	271
20 to 50	1,792				0.302	541
Other Forest Species	3,502					877
85+	1,159				0.877	1,016
50 to 85	1,287				0.512	658
20 to 50	1,056				0.318	335
						2,010
Total Commercial	14,737				0.488	7,998
Total Commercial Forest	14,737				0.488	7,998
Productive Reserved Forest	1,396				0.488	681
Other Forested Lands	5,778				0.391	2,259
(< 20 CU. ft./acre)						
Total Forested Lands	**21,910**					**10,937**

1987 Data from PNW-RB-168 (Waddell, et al) from Birdsey, 1992 (acres by species and productivity classes prorated from Conner).

Table C. Year 1992 Forest and Woody Biomass Stocks Increment

	Column A Area of Biomass & Forest Stocks (1,000 acres)	Column B Annual Growth Rate (Tons DM/ Acre/Year)	Column C (A*B) Annual Biomass Increment (1,000 tons of DM/acre/yr)	Column D Carbon Fraction of DM (tons C/ ton DM)	Column B (revised from Birdsey, 1992) Annual Growth Rate (tons Carbon/ Acre/Year)	Column E (C*D) Total Carbon Intake Increment (1,000 tons C per year)
Commercial Timberlands						
(> 20 cu. ft./acre/yr)						
Douglas Fir	5,674					
Lodgepole Pine	3,716					
Ponderosa Pine	2,699					
Other Forest Species	3,775					
Total Commercial	15,863					
Total Commercial Forest	15,863				0.488	7,741
Productive Reserved Forest	2,060				0.488	1,005
Other Forested Lands	4,589				0.391	1,794
(< 20 CU. ft./acre)						
Total Forested Lands	**22,512**					**10,541**

1992 Data from (Powell, et al) GTM-Rm-234) (species acres prorated from O'Conner and O'Brian, 1993).

Table D. Changes in Forest and Woody Biomass (All Removals)

	Column F Amount of Commercial & Wood Products Removed (from Conner and and O'Brien, 1993) (1,000 Cu.Ft.)	Column G1 Above-ground Ratio: Ratio of Total Above-Ground Volumes to the Merchantable Volume (Tbl 1.1 USEPA,1995)	Column G2 Carbon Factor Conversions (Index #'s from Table 1.2 USEPA, 1995)	Total Carbon (columns F*G1*G2) w/ ton conversions Total "C" Removals Increment (1,000 tons "C"/yr)	Molecular Weight Conversion Factor	CO_2 Total Carbon Dioxide Equivalent (1,000 tons "CO_2" per year)
Commercial Timberlands						
(> 20 cu. ft./acre/yr)						
Douglas Fir	71,279	1.898	15.11	1,022		
Lodgepole Pine	63,401	1.898	11.86	714		
Ponderosa Pine	41,476	1.898	13.29	523		
Other Forest Species	73,572	1.898	13.42	937		
All Commercial	249,728	1.898	13.61	3,225		
Total Commercial Forest	249,728	1.898	13.61	3,225		
Productive Reserved Forest	0	1.898	13.61	0		
Other Forested Lands	?	1.898	13.61	0		
woodland< 20 Cu.ft./acre/yr.						
Totals	249,728	1.898	13.61	3,225	44/12	11,827
(including rounding errors)						Tons CO_2 (1,000's)
Commercial Forest						
fire, insect and decay loss	73,900	1.898	13.61	954	44/12	3,500
						Tons CO_2 (1,000's)
Total Releases	**323,628**	**1.898**	**13.61**	**4,180**	**44/12**	**15,326**
			Tons C (1,000's)			Tons CO_2 (1,000's)
			Removed in 1990			

Appendix B.
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